In Two Sections—Section 1

Electrical Engineering

December 1938

Published Monthly by the
American Institute of Electrical Engineers

To Measure—VIBRATION ELECTRICALLY

Measuring vibration of large punch press

VIBRATION is that pulsing, throbbing motion with which you are familiar—in machinery, in office buildings, even in a house. Seldom can you see it; more often only the finest sense of touch can detect the vibrating movement.

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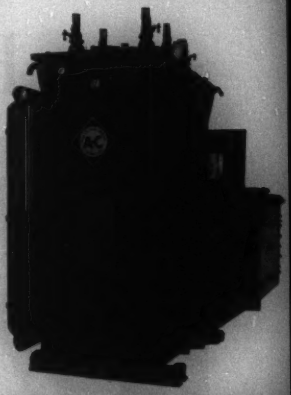

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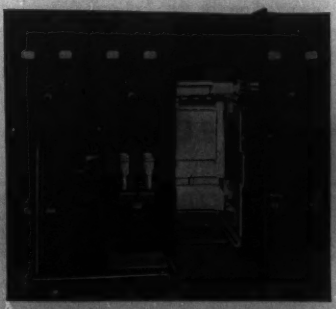

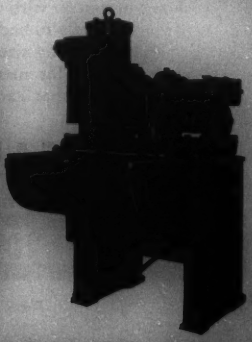

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Electrical Engineering

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The Cover

One of the new 3,600-horsepower electric locomotives of the New York, New Haven and Hartford Railroad. Total weight is 432,000 pounds; total length, 77 feet

General Electric photo

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High Lights

1938 Reference Index. For the convenience of members and readers, the annual multi-entry reference index to material published by the AIEE during the year 1938 is published in pamphlet form as Section 2 of this issue of ELECTRICAL ENGINEERING. As an added convenience, this index is divided into two parts: Part one covers general-interest articles and news items; part two covers all technical papers and discussions published in the 1938 TRANSACTIONS, including both those preprinted in the monthly sections of ELECTRICAL ENGINEERING and those published only in the TRANSACTIONS volume, which are being reprinted in the "TRANSACTIONS Supplement." Thus, those who have ordered copies of the Supplement will find all papers contained in that publication listed in this index.

Circuit Breakers. A new multibreak interrupter that is applicable to conventional tank-type high-voltage oil circuit breakers has a pressure-generating gap associated with each interrupting gap to force oil between the parting contacts (*Transactions pages 705–12*). To determine whether a 138-kv oil circuit breaker would perform successfully under severe duty on a system of high capacity, a series of field tests has been conducted on a large power system (*Transactions pages 696–705*).

Engineering and the Law. Many new legal problems have arisen out of the new developments in the social structure brought about by engineering and scientific achievements. While today engineers assist lawyers materially in situations where engineering questions are involved, there is an opportunity for broader service through a closer co-operation between the engineering and legal professions (*pages 477–9*).

Characteristics of Triodes. If vacuum tubes be operated with their grids strongly positive during a short interval in each cycle, the usual equation for plate current, used for negative or low positive grid potentials, is not valid for large positive grid potentials, but may be modified to produce dependable results (*Transactions pages 693–6*).

Remote Control. Omission of the customary master relays, phasing relays, and associated current transformers from network protectors in a low-voltage a-c network, and substitution of a remote-control system of pilot wires operated from relays at the supply substation, may provide a reliable installation at economical cost (*Transactions pages 685–92*).

Value of AIEE to the Engineer. "The Institute will realize its fullest value to the membership when as many as possible of the 15,000 members are participating in some way or other in the conduct of their professional organization" said AIEE President John C. Parker in an address at a recent Section meeting (*pages 506–07*).

Petersen Coils. Careful analysis of the characteristics of a power system has been found to be necessary before applying Petersen coils, which are intended to reduce outages by extinguishing the arc at the point of fault without the operation of circuit breakers (*Transactions pages 663–76*).

Fluorescence. A property of many substances, fluorescence consists of an emission of light under excitation by radiation of a wave length within a critical absorption band, and is associated with the presence of a specific ingredient at low concentration (*Transactions pages 677–81*).

Glass Insulation. Fiber glass now has been developed to the point where it can be woven into tape for insulating the windings of electrical machines. Its ability to withstand high temperatures makes it particularly adaptable to use in railway motors (*pages 480–3*).

Lightning. During the past four summers, lightning strokes to the 1,250-foot Empire State Building in New York, N. Y., have been studied, and many records have been obtained by means of the Boys (moving lens) camera and cathode-ray and crater-lamp oscillographs (*pages 493–505*).

Research and Progress. Continued research and development is necessary for technical progress, as is proved by the mortality of business enterprises not engaging in research whose products are permitted to fall behind and become obsolete (*pages 484–8*).

Memory Attachment for Oscilloscope. For obtaining oscillograms of "random phenomena and events immediately preceding and following their occurrence" a device known as the "memnoscope" has been produced (*Transactions pages 682–5*).

Winter Convention. Two general sessions with speakers of national repute and technical sessions on a wide variety of subjects are being scheduled for the AIEE 1939 winter convention to be held in New York, N. Y., January 23–27 (*pages 508–09*).

Chemistry and Dielectrics. The chemist, as well as the engineer and physicist, has an important role to be played in the successful solution of problems in high-voltage dielectric engineering (*pages 489–92*).

Correction. In the article "Graphics in the Solution of Complex Quantities" by E. C. Goodale in the November 1938 issue, sentences three and four of paragraph one, page 453, should read: "The electrical quantities of a series circuit are determined most simply by finding first the impedances of the parts that are in series, then solving for the common *current* (if it is not given) and for the voltage drops. A multiple circuit is solved most simply by expressing it in terms of its admittances, then solving for the *common voltage* (*if it is not given*) *and for the* currents in the branches." The beginning of the third paragraph in the second column should read: "From the similar triangles OUB and OAB'," and the end of the first paragraph on page 454 should read: "From the similar triangles OAB and OUB'."

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: two articles on the professional phase of engineering education—one discussing the subject from the viewpoint of professional registration, by P. H. Daggett (A'08) and the second presenting an industrial viewpoint, by O. W. Eshbach (F'37); articles based upon two papers presented at the Seventh International Management Congress—one on management's responsibilities to society, by A. W. Robertson (A'27) and the other discussing the influence of technical progress upon social developments, by K. T. Compton (F'31); an article reviewing the year's progress in insulation research, by J. B. Whitehead (F'12); an article presenting a summary of recent actions pertaining to the meter-kilogram-second (Giorgi) system of units, by A. E. Kennelly (HM'33); a paper on traveling waves initiated by switching by L. V. Bewley (M'37); five papers on the co-ordination of mathematics, physics, and electrical engineering subjects in engineering schools, by J. M. Bryant (M'13), W. A. Curry (F'37), M. G. Malti (M'34), T. H. Morgan (M'31), and B. R. Teare, Jr. (M'36); a paper on the application of capacitance potential devices by J. B. Clem (M'30); a paper on the flash-over characteristics of transformer capacitor bushings by H. L. Cole (M'21); and a paper describing a current-limiting power fuse by D. C. Prince (F'26) and E. A. Williams, Jr. (A'37).

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Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

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Engineering and the Law

By CHARLES W. APPLETON

New developments in the social structure, brought about by the results of scientific and engineering achievements, have increased the intricacy of legal problems tremendously. By working together, the lawyer and the engineer undoubtedly can contribute more than they have in the past through wider appreciation of the economic and social problems involved.

IN THE OLD DAYS a lawyer's business consisted largely of writing deeds, running down titles, making and breaking wills, convicting horse thieves, and bringing lawsuits about line fences. But how things have changed, with the improvements in the steam engine beginning with Sickles' drop-cut-off or detachable valve-gear, the growth of rail transportation, the expansion of the steel and textile industries, and the advent only yesterday of the steam turbine, automobile, airplane, and radio—all engineering creations—to say nothing of the dynamo and the motor, electric traction, elevated railways, electrified subways, and the great public utility companies.

It is notorious that during the heyday of this development, the legal profession flourished like a green bay tree. Think of the damage and injunction suits, condemnation proceedings, franchise disputes, railroad collisions, industrial accidents, and lawsuits arising out of contamination of the air and water. The disputes became so numerous and often the dockets of the courts were so clogged that the legislatures had to come to their relief and establish special machinery to take up the overload so that they might again function at their rated capacity.

There is a general impression that the law and the legal profession, and *not* engineering, is at the bottom of most of the annoyances and unpleasantness that afflict us, but I think that this idea comes from a failure to understand what the law really is. I am speaking, of course, of the common law inherited from England, which is rather figuratively spoken of as having been brought over on the Mayflower, and is in truth the glass in which democracy sees its feature and its form. The common law and the democratic institutions are as warp and woof, and a change in one has its inevitable repercussions on the other. Wrought for almost a thousand years as on an anvil out of the experience of the English-speaking people, recorded in countless books of law reports containing the printed record of millions of actual court decisions, it expanded step by step to attempt to adjust and reconcile and, as it were, to absorb and digest the new problems created by the rise of the scientific age. Dealing thus with the outburst of invention, the startling expansion of engineering applications, the introduction of the factory system, the dislocation of the domestic economy, and the bewildering increase in the complexity of social relations, it forms a heritage, the like of which is possessed by no other nation on earth.

One can think of law as an engineer or scientist thinks of electrons, atoms, molecules, attractions and repulsions, strains and stresses, masses. The individual is the electron; the atom the family; the molecule the corporation, association, village, or other small organized group; the masses the city, state, and similar large administrative divisions. The attractions and repulsions, the strains and stresses, the interrelations, the valences, as it were, are the rights and duties that law is designed to measure, evaluate, weigh, and enforce.

There have been innumerable definitions of "law," and thousands of books have been written on the subject. This arises from the fact that it is a general term and in its broadest sense means a rule or principle of action or reaction and may embrace anything from the laws of physics and chemistry or of the universe, to the moral law, the Roman or civil law, or so-called natural law.

Law in the sense that I am using it is the law that faces one when he is arrested or becomes involved in a lawsuit, and which is administered by the judges and juries sitting in the imposing court houses that may be seen in every county and city in the land.

The court decisions or "cases" may be taken as borings or samplings from a mine of experience of incomparable richness. They are all classified, arranged, and pigeonholed so that any trained lawyer can refer to them on the shortest notice. Many of the strange words and phrases in deeds and formal documents are actually inheritances and survivals from these ancient times. Many jokes have been built on the idea that lawyers are the slaves of precedent, but what would engineers, what would any learned body give if they had a written record of as many tests! And perhaps lawyers are not alone in being creatures of habit—only frank enough to admit it.

Now I am afraid that the conception of law entertained by engineers and many others is quite different, because in their daily work they are more likely to find themselves annoyed or thwarted as by the provisions of a city ordinance, regulation, or state statute, providing for inspection or the approval of a board, and they stand aghast at the flood of new statutes enacted annually by the states and the Federal Government. Well, the courts and lawyers must recognize these just as all other groups and citizens

Essential substance of an address presented at a meeting of the AIEE New York Section, October 19, 1938.

CHARLES W. APPLETON is vice-president of the General Electric Company, New York, N. Y. He received the degrees of bachelor of science from St. Lawrence University (1897) bachelor of laws from New York Law School (1899) and doctor of laws from St. Lawrence (1929). After several years of private law practice in New York, N. Y., he was successively assistant district attorney, New York County, 1903–10; instructor, Brooklyn Law School, 1909–18; city magistrate, New York, 1910–18. He became counsel of the General Electric Company in 1918 and was elected a vice-president in 1927.

do, but the lawyer thinks of them as *laws* and not as law. They are the result of action by the legislative and not the judicial branch of the government, but may come before the courts for interpretation either as to their meaning or their conformity to the basic law of the land.

Numerous as these laws seem to be, they are after all a mere fringe on the body of the law and in many instances are made necessary to deal with situations to which the processes of litigation often are unsuited or inadequate because of the suddenness or rapidity of the social changes created by engineering and scientific developments. But under and above it all is that great fundamental "law of the land," recognition of which by King John was compelled by the barons in Magna Charta in 1215, and which has been defined better than anywhere else by Daniel Webster in his argument in the famous Dartmouth College case where the New Hampshire legislature, without its consent, had attempted to alter the charter of the corporation granted to it by the British Crown. "By the law of the land," said Webster, "is more clearly intended the general law, a law which hears before it condemns; which proceeds upon inquiry, and renders judgment only after trial. The meaning is that every citizen shall hold his life, liberty, property and immunities, under the protection of the general rules which govern society." Not every enactment or statute passed by the legislature, not all "laws," said he, are *law* unless they conform to the fundamental law of the land, and in this case the charter was a contract that could not be impaired and that even the American revolution had not dissolved.

Now what are the methods, what is the technique of the law? Manifestly as new developments in the social structure, in science, invention, and engineering are brought before the courts, they cannot rely on the precedents because the force or apparatus is an entirely new one or is given a new application. Naturally questions arising in connection with them never before have come to the courts for adjudication. Therefore, no other course is left but the resort to analogy in an attempt to find a guiding principle.

Let me illustrate how they dealt with electrical phenomena. Of course, only scientists and engineers knew what electricity was in 1779 when Volta discovered that it flowed, or when in 1825 Sturgeon found he could make an electromagnet, or when in 1831 Faraday made the first dynamo, and Edison later established his central station, or when Stanley came along with his transformer in 1886, the year in which a whole galaxy of engineers rose above the horizon like the sun in its chariot and the a-c era began.

Out of a clear sky, as it were, a multitude of legal problems arising out of this fearful progeny of the thunder cloud were laid at the door of the courts—mysterious forces that disturbed the telegraph and telephone, that gnawed at the service pipes and iron structures, that disturbed the electric lights. What were they? Was priority to control? Was first in time, first in right, according to the old maxim? If adjustments were possible, should they be compelled, and if so, who was to make them, and how was the expense to be apportioned? Could any one do as he pleased on his land so long as he was skilled in his art, or did he act at his peril if his neighbors were injured or annoyed? Heretofore the owner of the surface had owned from the center of the earth to the top of the sky. As an early lawyer who was used to calling a spade a spade expressed it: "He who owns the soil owns all above and below from heaven to hell." The land law which grew out of the feudal system was the most ancient, the most certain, the most unalterable of any part of the common law. The highways were laid out for passage and travel on foot or horseback, possibly with horse and buggy.

Lawyers and courts turned to the nearest analogy. If one gathered water on his land in unnatural quantities, as by a reservoir and it escaped to the injury of another, it had been held that he was liable in damages. If he harbored a vicious animal and allowed it to escape, again he was liable. If even on his own premises he created a noise that disturbed his neighbors, or poured noxious fumes into the air, or polluted the common stream, again he must respond in damages to those who suffered from his acts. While it was conceded that one might do what he would with his own, there was a corollary to this to the effect that he must do so without injuring another who had rights of his own. With some such reasoning, the courts approached problems of electrolysis, of inductive interference, and are today wrestling with radio interferences as related to the use of diathermy apparatus; and before long we may prophesy X-ray and ultraviolet insulators and other electrical phenomena and devices.

The development of aviation and broadcasting present two other areas of conflict. By the old law, the owner of the surface had the rights to which I have referred. But the law does not indulge in theory, and when a real case arose the plaintiff had to show that he suffered damage or that the person using the air had created a nuisance, and this he was seldom able to do. Since airplanes covered such vast distances in so short a time, and courts as a rule could function over only limited areas, prevention rather than post mortems appeared to be in the public's interest. Therefore, Congress passed a statute regulating air traffic and empowering the Secretary of Commerce to formulate rules dealing with the altitude above the earth that the pilot must follow and other matters. While it may seem that this made a change in the law, as a matter of fact the legislative act is merely an attempt to reduce the hazards, to minimize litigation, and facilitate the growth of the art. Again, the new legal problems growing out of broadcasting are staggering in their import, with their effect on the freedom of speech, liberty of the press, and even international relations. These problems today stand at the door of the courts; and we may be sure that through the due processes of the law of the land, supplemented and augmented here and there by legislation, their solution at last will be found. But this is not the end. There will be no end until, in the words of Kipling, "earth's last picture is painted."

Need we ask how the courts will approach the problem of the stratoplane when it begins to interfere with the ancient art of flying in the nether air and to crowd the regular users from the landing fields? Wasn't the air made to fly in, just as the streets and highways were laid

out to walk on or travel on with horse and buggy?

What a wonderful thing it would have been if earlier in this period of development lawyers and engineers could have had a better understanding of each other's problems and had worked closer together to anticipate their solution on a basis that would command public support, having regard to the daily increase in the complexities of social relations and the consequent problems of legislation and government. Then we might have had less public regulation and more self-regulation, fewer entangling ordinances and battalions of inspectors, and a lesser flood of legislation.

The work of the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone System composed of eminent lawyers, executives, and engineers and dealing with physical relations between electrical-supply and signal systems is a striking example of what might have been accomplished. It is "too late to cry over spilled milk," but it is not too late to look ahead to the end that we may profit by the experience of the past as we approach the problems that lie ahead. As in the past, I believe that the burden will continue to rest upon what seem to me to be the great pillars of our social and economic system—engineering and the law.

There was a time when men of good intellectual and moral parts, like Washington, Jefferson, and Franklin, could comprehend, and as it were, encompass the phenomena of the times in which they lived and give them direction. But granted that we have men with equal intellectual power and love of country today, how enormously more difficult is the task with all the new forces and developments to which science, engineering, manufacturing, and methods of distribution have given birth.

Today we are floundering in a morass of uncertainty in so many directions just because, as it seems to me, we are "a prey to economic illusions," in the language of Justice Holmes, and are afraid to look facts in the face. Courts that are untrained and inexperienced in business and economics attempt to adjudicate problems of business and economics. Doctors of philosophy and economists attempt to deal with law who do not understand what law is and are, therefore, without power to evaluate it.

While I would not imply that engineering does not deal with human relations, by and large it seems to me to be concerned with mathematics and the physical sciences and to be primarily concerned with investigating, evaluating, planning, and designing works, structures, buildings, machines, equipment, and processes, which have brought about such a revolution in our mode of living and are the real culprits that have brought about the necessity for so much legislation. But simplification, elimination of useless parts, generalization, ascertaining the common denominator are second nature to the engineering profession, and it is qualities like these that are needed so sorely today as we face the entanglement of conflicting statutes and such a multiplication of "dos" and "dont's" that the ordinary business man and engineer often stand aghast.

Could the two great stable forces of engineering and the law make a greater contribution to public peace and order than by not being too puffed up with professionalism and dealing with the problems as plain citizens, equal members of society by organization, co-ordination, and conscious training? We know that today engineers assist lawyers materially in the preparation and trial of cases where engineering questions are involved. They also frequently are requested to assist municipal engineers in the preparation of ordinances and codes. They also sit on committees charged with the preparation of codes sponsored by different national bodies, and these codes are adopted by municipalities throughout the United States. Why more of them do not seek election to the state and federal legislatures, where they could perform such a wonderful service, perhaps the engineers themselves know better than I.

We must recognize that in our own lifetime the engineers, in effect, have built a new material world. This probably is due to the rapid development of the production and use of electricity, but it applies to all the labors and avocations of man. Men produce more in a given time, travel faster, get world news more quickly, and, in their leisure, have more time for consuming the products of their labor. Still production and consumption are far from synchronized.

The engineer really never is satisfied with the industrial world or any of its devices. He is constantly seeking means to do a given job better and for less cost; higher efficiency and lower operating expense; greater output and smaller unit cost. The engineer is always looking ahead. He never is satisfied unless his enterprise is contributing each year new inventions and improvements on past inventions designed to bring greater benefits to mankind.

The lawyer, however, is generally called in after something has been done that presents a problem dealing with the past—either in the immediate or distant past—and in his consideration of the laws affecting these problems and in counsel to others, he, in effect, must take into consideration the changes in the lives of the people brought about by engineers in industrial development. Certainly the lawyer like any other enlightened citizen does not want to see less made or to give encouragement to those who would advocate curbs on enterprise or production. If the objective of the engineer is correct in working to provide more things for more people at less cost, the lawyer and the engineer, working together, undoubtedly can contribute more than they have in the past through wider appreciation of the economic and social problems involved.

When new developments conceived by the brains of engineers come into being and become a part of our industrial development, the engineer has a right to feel justly proud of his contribution to society. Possibly, by the success of his development, he is spurred to make others; but somewhere along the line someone must design a plan for adapting this new development in our economic life so that it will accomplish the benefactions that spurred its development.

Is it not in this field of engineering, government, and law, dealing realistically with things as they are and not as we would like them to be, that the lawyer and the engineer, each with that broader conception of his separate field of endeavor and his characteristics, can make an added contribution to the welfare of all the people?

Fibrous Glass for Electrical Insulation

By R. E. FERRIS G. L. MOSES

Development of fibrous glass yarn has provided a new insulating material that will withstand high operating temperatures for use in electrical machines

GLASS long has been recognized as excellent electrical insulation, but until recently its use was limited by the form in which it was available to the electrical industry. As a hard, brittle, vitreous material it had definite and rather narrow limitations. With the development of fibrous glass yarns a vast new field has been opened to its use electrically. Its great flexibility, high tensile strength, and resistance to deterioration at high temperatures make it a universally applicable insulation material.

The art of spinning glass into threads of such a size to be used in textiles is not new. However, it was only recently that processes and machinery were developed for producing these minute glass fibers cheaply in great quantities of uniform size and quality. The fibers produced vary from 0.0002 to 0.0003 inch in diameter and are made by two basically different methods.

The "staple fiber" process was first developed and consists of a flow of molten glass through small holes in a platinum bushing in combination with steam pressure. The fibers fly out in short lengths (usually 4 to 12 inches long); these are picked up on a revolving drum and then are spun into yarn and woven into cloth by processes similar to those used by the cotton industry.

Written especially for ELECTRICAL ENGINEERING.

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The "continuous filament" process was developed subsequently and consists essentially of drawing the molten glass through fine holes in a platinum bushing. The filaments are wound on rapidly revolving spindles which draw out the molten glass, thereby reducing the size of the filament. In this process the speed of drawing the finished filament controls the diameter. Yarn is spun and woven by processes similar to those used in the silk and rayon industry.

Both processes utilize electric heat for melting the glass. The material is fed into the heating unit in the form of glass "marbles" and the quantity carefully is metered to maintain the molten glass at a constant level. A single "marble" three-quarters of an inch in diameter can be spun into an almost invisible filament approximately 70 miles long.

Since ordinary soda glass is slightly soluble in water it was found necessary to develop a new formula. "Alkali-free glass" was the solution, as it is resistant to moisture. In addition, it has better electrical characteristics, the insulation resistivity being much higher, and it varies less with temperature changes.

Glass fabrics are 100 per cent inorganic and do not deteriorate in mechanical or electrical characteristics at temperatures far above operating temperatures permissible under AIEE rules for class *B* insulation (inorganic materials such as mica and asbestos in built-up form combined with binding substances). Glass tape wrapped around tubes takes a permanent set at 732 degrees centigrade. The "strain point" is 807 degrees and the softening point is 835 degrees centigrade. The industry has far to go before approaching such operating temperatures in electrical machinery.

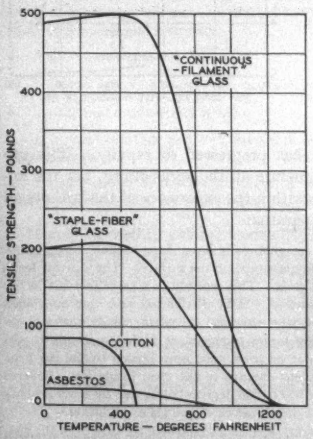


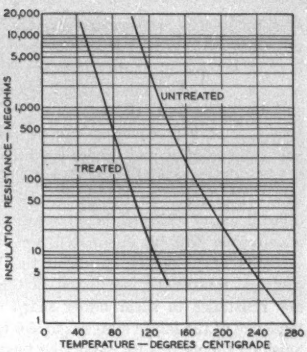
Figure 1. Effect of heat on tensile strength of fibrous electrical insulating materials

Measurements made on tapes 0.01 inch thick by 1 inch wide

The tensile strength characteristic curves of glass tapes (both staple and continuous) are shown in comparison with asbestos and cotton in figure 1. It is significant

Figure 2. Effect of temperature on insulation resistance of glass tape

Measurements made on test coils having 6 layers of tape 0.01 inch thick built up to a total thickness of 0.06 inch and contact area of 82 square inches



that both types of glass improve in strength until a temperature of 400 degrees Fahrenheit (204 centigrade) is reached. At that temperature cotton tape deteriorates rapidly and asbestos begins to deteriorate. Staple tape is stronger at 800 degrees Fahrenheit (426 centigrade) than cotton at 25 degrees centigrade, and continuous tape is equally as strong at 1,000 degrees Fahrenheit (538 centigrade).

As a dielectric, dry untreated glass tape is comparable with asbestos as both are porous woven materials. Their dielectric breakdown is approximately the same as that of air. When treated, both partake of the characteristics of the impregnating varnish. Glass has the advantage of being nonhygroscopic and has a higher dielectric breakdown than asbestos after exposure to humid atmosphere. Tests indicate that glass (whether treated or untreated) will withstand $1\frac{1}{2}$ to $2\frac{1}{2}$ times the voltage that asbestos will when both have been exposed to relatively high humidity.

When dry and untreated, glass has a resistivity many times greater than that of asbestos; when treated, they have approximately the same order of resistivity. Figure 2 shows the relative values of insulation resistance for glass insulation on test coils both untreated and vacuum impregnated in solventless varnish and the effect of temperature. When exposed to humidity, glass maintains its insulation resistance to a much higher level. Figure 3 illustrates this on similar test coils insulated with glass and asbestos when both are impregnated in solventless varnish. The insulation resistance of the asbestos-insulated coil fell to 0.5 megohm and failed in 13 days. At 13 days the glass-insulated coil had a resistance of nearly 2 megohms and the curve rapidly was flattening out. The glass-insulated coil did not fail. Figure 4 shows the effect of exposure to various humidity conditions on insulation resistance of glass and asbestos tape.

The insulation of wire is one of the most important applications of glass fibers. The excellent mechanical strength and its resistance to cutting under pressure (where no sharp corners are present) make it well suited to stand abuse in winding and in service. Its ability to withstand excessive temperatures puts it in a preferred position for use as wire insulation in coils that must operate

at elevated temperatures or those that may be subjected to occasional severe overloads. Most glass-covered wire is given an enamel treatment to ensure holding the fibers in place. It is possible to apply glass fibers to wire in any thickness from the equivalent of silk on up. The thickness of wire covering can be selected to suit the particular winding and service conditions.

Like all other materials, glass textiles have their definite limitations. In the present state of the art it is difficult to say which of these limitations are inherent and which soon will be eliminated by further progress in methods of producing or using the basic fibers. The principal limitations recognized at the present time are low resistance to shear under sharp cutting edges and tendency of the fabric material to slip because of the silky finish on the yarn. By modifying the technique of handling in the shop, the effect of both these can be minimized. When applying glass fabrics the material should not be snubbed in tension. New weaves are being developed to produce denser cloth with the same thicknesses, which also will counteract the tendency to slip. A practical method used by the authors to counteract this slippage is to vacuum impregnate the rolls of tape in solventless varnish and only partially cure. This is very satisfactory and improves the coil finish. By avoiding sharp edges in applying glass tape, difficulty from the tendency of this material to cut easily will be minimized. Experience indicates that so long as a definitely sharp edge is not present its mechanical strength is high.

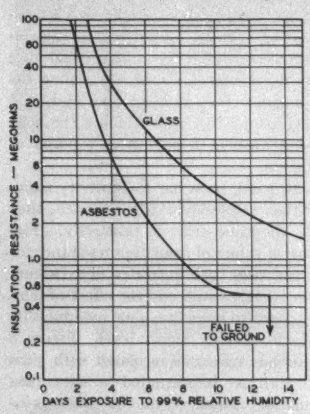


Figure 3. Effect of exposure to relative humidity of 99 per cent on glass- and asbestos-insulated coils impregnated with solventless varnish

Glass insulating materials are available in the following forms:

1. Tape. This is available in any standard thickness or width. The present limit on minimum thickness is 0.003 inch for continuous-filament tape, and 0.010 inch for staple-fiber tape.

2. Braided Sleeving. This is made from continuous-filament yarns in many standard inside diameters.

3. Glass-Insulated Wire. All sizes of round wire are being covered successfully with glass yarn, and many sizes of square and rectangular wire have been covered. Various thicknesses of wall are being used, depending upon the application, to produce an insulated wire size corresponding to standard asbestos-covered, cotton-covered, enamel and paper-covered, and silk-covered sizes.

4. Woven Cloth. This is available at present in thicknesses of 0.002 inch and upward.

5. Combination "Glasweve" and Mica. Combination slot cells of glass cloth (or mat) and mica splittings are being developed which may result in a higher class *B* insulation for this application.

Textile glass insulation has been used in almost every conceivable application within the few months in which this development has progressed so rapidly. It is impracticable to enumerate all the applications, but the following have come within the experience of the authors on transportation apparatus:

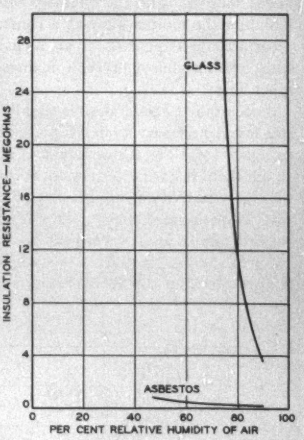


Figure 4. Effect of humidity on insulation resistance of asbestos and glass tapes at 100 degrees Fahrenheit (38 centigrade)

Measurements taken on 0.025- by 1-inch tapes after temperature and humidity had been held constant for 72 hours

1. Many styles of magnet coils have been wound using glass-yarn-covered wire and glass tape on the surface. The starting leads also were taped with glass. This resulted in a great increase in life at very high temperatures. Heat dissipation also was improved. The resistance of the wire covering to cutting under pressure resulting from expansive forces produced at high temperatures was astounding. In laboratory tests, coils were heated to the red heat of copper without serious damage to the glass insulation. Several coils were operated at 500 to 550 degrees centigrade for several hours without any apparent deterioration of the glass insulation.

2. Field coils taped with glass were found to have increased strength of outer insulation and to be more resistant to deterioration at extreme temperatures. Improvements in treatment and appearance of finish were also obtained.

3. Armature conductors were insulated by taping the conductor and by spinning on glass yarn (in the same manner as cotton and silk are applied). This was found to increase the relative life and reduce the probability of short circuits.

4. Armature coils were made using glass binding tape and finishing tape. These withstand higher temperatures without deterioration, and considerable space can be saved over asbestos-taped coils.

5. Armature-coil leads have been sleeved with glass sleeving, or taped with glass tape. This saved considerable space at a crowded spot, and reduced damage from pounding while the armature was being wound.

A relatively large number of commercial applications of glass insulation have been made on railway and trolley-coach equipment which is in everyday service. Several modern high-speed railway-motor armatures and fields have been taped with glass, and a few traction-motor armatures have been wound with glass-insulated wire. On older railway motors, armature coils are being made with glass tape on the outside and on the leads. Many renewal armature coils have been made for high-speed railway motors with glass sleeving on the leads. Traction motors for a prominent a-c main-line electrification had the stator coil ends taped with glass. Many railway control magnet coils have been insulated with glass tape and all have been in operation for several months without trouble. Many magnet coils have been made with glass-insulated wire. Much new transportation apparatus is being built using glass insulation because of the advantages obtained by better space factor and high-temperature operation inherent in glass insulation.

The following is a summary of the advantageous characteristics inherent in textile glass insulation:

1. It is capable of operation under high-temperature conditions, being noninflammable.
2. It has great tensile strength which is maintained to relatively high temperatures.
3. The insulation resistance and dielectric-breakdown strength are both relatively high and are affected less by moisture than are those of conventional materials.
4. The material is nonhygroscopic.
5. It resists attacks by acids, oils, corrosive vapors, and vermin.
6. Its thermal conductivity is high.
7. It is more resistant to a combination of abrasion and vibration than asbestos.
8. Impact, except by a knife edge, can be withstood much better than by corresponding asbestos and cotton tapes.

It may be well to enlarge somewhat on the possibilities of increased temperatures by the use of glass insulation on transportation apparatus. The AIEE rules have defined class *B* insulation in such a way as to permit the use of an indefinite amount of class *A* insulation for structural purposes. For temperatures within the range specified by the rules, this combination material has been very satisfactory, since the maximum temperature for this class of insulating material was established with this limitation in mind when such combinations of organic and inorganic materials were all that was available. However, at temperatures considerably higher than those specified by the rules, the class *A* content of the insulation deteriorates to such an extent that difficulty if not actual failures sometimes will be experienced due to shrinkage of the insulation.

Glass insulation used as a binder and mechanical support in combination with mica offers the possibilities of an insulation that is practically 100 per cent class *B* (except for the treating materials) and thereby places the limitation of temperature on the treating material. This may not be a limit at all on some types of transportation apparatus where high continuous temperatures are encountered, thereby eliminating the possibility of moisture, or in intermittent service where there is little likelihood of moisture absorption. Such a material need not have the same temperature limitations as earlier forms of class *B* insulation, as its aging characteristics under high temperatures will be quite different. It is particularly desirable on transportation apparatus to have insulation that is capable of withstanding temperatures above the nominal upper limits, even though the apparatus may be rated at the conventional temperatures.

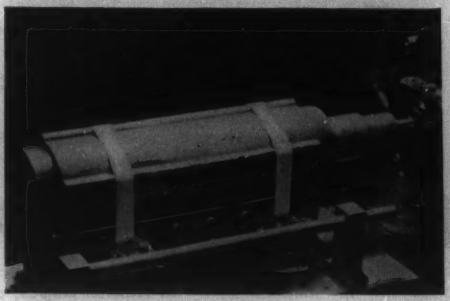


Figure 5. Abrasive life test of glass tape in comparison with other insulating materials

Higher temperatures are, of course, only a means to an end, this end being one of three important characteristics or a combination of all three: first, reduction in size of a machine for a given rating; second, reduction in weight; and third, under certain conditions, a reduction in cost per unit rating. All three are of particular significance in the field of transportation. It is outside the scope of this article to discuss the design of machines operated at higher temperatures, it is not sufficient simply to attempt to increase the rating of a given machine by increasing the volt-ampere input or output. The designer, in order to take full advantage of higher temperatures, must balance his design as regards copper, iron, and stray-load losses. Efficiency must be given consideration in d-c machines, and efficiency and power factor in a-c machines.

Such considerations as expansion and contraction are involved in the use of higher temperatures, but the authors believe that at present the "bottle neck" of the problem is the development of treating material that will withstand higher temperatures. This is in the hands of the chemists whose ability to meet such problems has been demonstrated many times. When this limitation is removed, the possibility of designing even smaller and lighter railway and aviation apparatus with a given rating will be increased yet further.

Much important development work has been done to bring the art of producing glass textile insulation and applying it to its present state. However, a great deal lies ahead in devising means of using its characteristics to best advantage, thereby still further advancing the industry.

The Importance of Research and Development in Maintaining Technical Progress

By M. W. SMITH
MEMBER AIEE

Research and development work usually are regarded as highly technical subjects and generally are so treated, but it is recognized that management has a very definite interest in their influence on technical progress, particularly in the industrial fields. This article is presented with this point in mind, and various suggestions and illustrations are offered as to how this kind of activity may be stimulated and more effectively controlled.

RESEARCH and allied developments are among the greatest factors contributing to the advancement of our standard of living. Through inventions resulting from its application we have traveled farther along the road of technical progress to a safer and more enjoyable life in the past hundred years than in all the preceding time. The last 25 years have surpassed all others and we can expect technical development to progress at an even faster rate in the future.

The scope of research is almost unlimited. It is effectively applied in almost every branch of the basic sciences. It influences the progress and trends of our industries, commerce, agriculture, public health and safety, employment, and even our national defense. While these various branches of research are broadly related and would be very interesting to discuss, it is considered desirable to limit this discussion to the field of industrial research with which the author is best acquainted, so as to indicate better in more specific terms some of the problems and responsibilities of management in the planning and administration of these functions.

Industrial Research and Development

There was a time, not so many years ago, when industry looked to the laboratories of the universities and endowed foundations for its research work, particularly in the fields of basic sciences. While it still recognizes the value of research done by these institutions and attempts to follow it closely through co-operation with them, industry is gradually assuming this responsibility even on fundamental work because results usually can be obtained more promptly by a more concentrated and continuous effort and by limiting the choice of fields of endeavor to those of greatest interest to the particular industry concerned. Although industry may concentrate its research in fields of its immediate interests, progressive companies also follow the work done in allied fields and in basic sciences even to the extent of maintaining fellowships in universities and other independent research organizations. They also maintain close contacts with foreign developments, and history reveals many instances where discoveries were made in one country and subsequently developed and commercialized in another.

Research is one of the most effective and certain means of protecting capital invested in industry from the decay of obsolescence. Reference was recently made in one of the financial papers to an investigation made by the investment divisions of several large insurance companies, to determine from an actuarial standpoint the mortality rate of certain kinds of businesses. One point on which they all agreed and placed considerable emphasis was that the companies which died invariably did little or no research. These companies just gradually "went to seed" with old products which were made obsolete by competitors who developed new methods, processes, and machinery to build products with more desirable performance and characteristics. A progressive company must not only protect itself against the creation of obsolescence from a competitive standpoint but industry in general must strive toward the creation of obsolescence as one of the most effective means of stimulating new business and prosperity. If new business had to depend entirely on the replacement of equipment and commodities which had been worn out or consumed, our progress would indeed be slow and our standard of living and employment would be stagnant. Only through the creation of obsolescence by the introduction of new and improved products can business expect to grow.

Unless we stop and reflect, we are likely to get the impression that our present industries and products have always been in existence, when as a matter of fact, probably one-fourth of our present production is of products entirely unknown 50 years ago, and even those that were known at that time have been modified and improved to such an extent that they can hardly be recognized as the same.

There was a time when business enterprises were quite firmly established and maintained for generations, but the last few decades have seen whole industries wiped out by the forward march of progress. Business men have not fully recognized this danger and adjusted themselves to it. There is still an instinct in the old to fight the new, but nothing except ruin can result from a strict

Full text of a paper prepared for discussion at the Seventh International Management Congress, Washington, D. C., September 19–23, 1938.

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adherence to such a viewpoint or policy where the new is something inevitable because of its economic advantage. A business man is not justified in abandoning an old, established business at the first sight of a substitute product, but neither is he justified in assuming that because it is a substitute for his product it is necessarily an enemy of his. By absorbing it or modifying his product through development work, he may find the opportunity to make his business more profitable than ever.

Aviation may alter seriously the railroad passenger business, but the railroads that have invested in aviation lines will win no matter which way the tide turns. Busses and trucking might put some railroad lines out of business but the railroads that own large bus lines and big trucking routes will carry the traffic in any event. That is the difference between just being in the railroad business and being in the transportation business.

Shortly before the advent of radiobroadcasting, there were probably at least 50 companies in the United States manufacturing phonographs. For a quarter of a century, many of them had done little or no research or development work. Almost overnight, a new form of audio entertainment appeared in the home. It immediately became apparent that the radio music and speech quality was vastly superior to that of the phonograph. Greatly decreased sales resulted in serious financial difficulty in spite of frantic advertising. However, a few of the most progressive companies promptly got in contact with radio experts, and after intensive research, incorporated in their apparatus electronic amplifiers, scientifically designed loud speakers, and electric recording with an astonishing improvement in quality. These companies soon began to prosper once more, while the others who ignored research and development promptly disappeared.

These illustrations emphasize the important part research and development play in the growth of industrial organization, but at the same time it must be recognized that even this activity can be carried to an extreme. Companies can also fail because of too much engineering and development expense if it is not effectively and efficiently controlled.

Types of Research

Depending upon its purpose, research and development in industry can be considered from various viewpoints, but for the purpose of analysis and study of functions and operations, it may logically be considered from the following three viewpoints:

1. Basic, or fundamental, research which involves studies and investigations at the frontiers of the basic sciences of physics, chemistry, etc., to determine the properties, characteristics, and behavior of matter quite without regard to any immediate or specific commercial uses or application.

2. Specific, or applied, research which is conducted to obtain definite information, solve a particular problem, improve an old product, or develop a new product or line of equipment.

3. Commercial development, which has for its purpose extensions to existing lines of products and improvements in their characteristics and performance. This type of development is not directed toward the discovery or perfection of new kinds of products, but toward improvements and cost reductions in existing ones so as to enhance their competitive standing or value.

Fundamental Research

The nature of fundamental research requires that it be undertaken on a comparatively long-range basis and the fact that important results or achievements may not be realized for several years should be recognized. Here the problem of management is largely one of the proper selection of personnel and general fields of investigations. The success of this kind of work is largely dependent upon individual effort and management can provide only limited detail supervision. The personnel must be selected with this point in mind. In addition to good technical ability and qualifications, men for this work should have an abundance of initiative, enthusiasm, courage, and imagination. The recognition of the importance of the selection and development of men for research work has been demonstrated by the establishment of special training courses and opportunities to do advanced work in industry.

For instance, the company with which the author is associated recently adopted a plan for the establishment of ten positions in its research laboratories, to be known as "research fellowships." These fellowships will be open to young scientific workers in physics, chemical physics, physical metallurgy, etc., enabling them to carry on studies of pure scientific value in these fields. Appointments will be made for a one-year period, with the possibility of renewal for a second year. Applicants are required to have training equivalent to a doctor's degree and have already demonstrated ability of a high order in scientific research. In this way it is hoped that a steady stream of the best young scientists will pass through the laboratories in years to come. While there are no definite committments, it is expected that some of these men will want to remain on the regular staff of the laboratories. Others will return to academic work in leading universities and other institutions after having acquired an insight into the scientific problems of the electrical industry. While the research fellows will be given considerable freedom as to the particular research problem on which they will work, it is expected that in all cases, the broad field of work will correspond to one of the existing activities of the laboratories. It is planned to keep the working program as flexible as possible in order to adapt it to current progress in physics and chemistry. Experience indicates that important advances in industry may be expected from fundamental knowledge gained through such a program and the operation of this projected fellowship plan should also serve to keep the laboratories in closer contact with other scientific institutions with which these men may later become associated.

Specific or Applied Research

Although specific, or applied, research cannot be sharply distinguished in all cases from fundamental, or pioneering, research, its purpose is different in that it is usually conducted with a definite objective in mind and with the idea of early application. It represents the major activity of

most industrial research laboratories because it is usually directed toward improvements in established lines of equipment. For instance, because of troubles experienced on a new product or because of the desire to extend the application of an existing product into new fields of application beyond previous limits of knowledge and experience, certain information and data may be necessary. This may require some fundamental research but it is largely a question of finding the answer to a problem which already exists and is not of a pioneering nature.

Because of its nature, applied research is often subject to the pressure of production from other divisions of the company, which have a commercial interest in the project. This condition, together with the fact that the management has an appreciation of the nature and scope of the problem, presents the opportunity, and even necessity, for much more supervision and direction of the work than can be expected on fundamental subjects. This kind of work must be followed closely and actively by the management to see that it progresses with reasonable speed and that specific projects are not drawn out beyond profitable limits. It is just as important to know when to stop an unpromising project as it is to start an attractive one. Moreover, the pressure for immediate results on specific subjects should not be allowed to crowd out fundamental work which is likely to be neglected because of budget limitations or because immediate requirements or prospects do not appear urgent.

Effective and efficient operation requires careful consideration of the organization and personnel and the classification of the types and scope of the work. In a large laboratory it is usually advisable to group the organization into several divisions with personnel and equipment best suited for work in a particular field or branch of science. This is particularly desirable if there are a large variety of subjects to be treated which can be grouped into general classifications. On the other hand, care must be used to avoid building barriers between divisions which will unduly limit the exchange of knowledge and experience between them. Quite often the knowledge obtained or the method of analysis or approach used in the solution of one problem may be quite helpful in attacking another. It is therefore desirable to set up effective systems and regulations for exchanging and disseminating information and results of investigations throughout the organization by means of adequate records, reports, seminars, conferences, etc. Adequate library facilities are also essential in this plan. All current literature should be carefully scanned and items of interest on various subjects should be summarized and referred to those particularly interested in or engaged in work on the subject. The practice of becoming thoroughly acquainted with the status of the art through surveys of existing literature before work on any new project is actively started should be encouraged.

Incubation of New Products

Out of basic fundamental research or even as a by-product of some specific research on another subject may come a new idea or product which has the possibility of commercial development and exploitation. Here management has a very definite problem and responsibility which often is neglected. A review of products which have come out of research indicates that few of them seemed to be important at the time they were first conceived. It is beyond the power of human conception and vision to recognize the future value and possibilities of many such developments and it is only after they have had an opportunity to spread their effect over a period of time that they are fully appreciated. Nevertheless, management must continually be alive to its obligations and take steps to encourage the practical development of new ideas and eliminate barriers which too often exist in their path.

An illustration of the obscure nature of discoveries is found in the phenomena connected with the discharge of electricity through gases. The faint glow discharges which it is possible to get in tubes with gas at low pressures first attracted only the scientists and physicists in the laboratory nearly 50 years ago. This toy of the scientist, however, led to two outstanding discoveries. The first was the discovery of the electron by Thompson, which historians will probably regard as the most important technical event to date. The second was the discovery of the X-ray by Roentgen, which has done much to alleviate human suffering and to prolong life, primarily because of its use for diagnostic purposes but also through direct treatment of disease.

The first attempts to use these glow discharges commercially were in the field of lighting, through the work of Moore and Hewitt in developing the mercury-vapor lamp. Today it is not the high efficiency which makes this type of light attractive, but the brilliant and unusual colors which are obtained in neon signs. Another development coming from these gas discharges is in the form of rectifiers and inverters for the electrical power field. One of the most recent applications of the gas-discharge principle, unforeseen in the early days, is the development of a special tube by Rentschler and James, which has very high lethal, or germicidal, powers.

Sometimes a specific development is not complete within itself, and other developments requiring research in allied fields must be completed and combined with it before a commercial success can be made of the idea. A better realization of this condition and responsibility by those in charge of the over-all activity should work toward the elimination of unnecessary delays in the progress of commercial development.

In 1880, a man by the name of Fritts, a pioneer inventor, filed a patent application on talking motion pictures. A review of this case will show that it contained practically all of the fundamental features which exist in the art at the present time. Yet the commercial application of talking pictures was delayed a generation because the elements called for were not promptly developed. For example, his photosensitive device would not respond to the frequencies of speech and music.

It is recognized that the progress of such basically new ideas necessarily must be slow because of human limita-

tions and lack of appreciation of future commercial possibilities. However, a better realization of this lack of appreciation and the acceptance of the responsibility on the part of management to see that steps are taken to develop component parts and principles instead of allowing new ideas and products to flounder around in the laboratories for lack of attention, should go a long way toward accelerating the progress of new developments.

Pilot Plants

Sometimes the difficulties encountered in promoting a new product of the laboratories are much more real and specific than the lack of vision to perceive their potential possibilities. Large industrial companies usually are organized into divisions which are responsible for the design, manufacture, and sale of established lines of products. They are likely to be reluctant to take over a new product until its market and profit possibilities have been determined. This condition often results in a long delay between the research development stage and the commercial application of the product.

To eliminate this unsatisfactory condition usually requires some intermediate stage of development. It is not practical to do commercial development work involving the study of manufacturing processes and cost reduction methods in a research laboratory. On the other hand, established operating divisions of a company, which are charged with the responsibility of making a satisfactory profit, cannot be expected to take over a new product until its commercial possibilities have been investigated. An intermediate organization is therefore desirable to carry the new product through the necessary incubation stage to determine its commercial value. Many of the chemical industries have solved this problem satisfactorily by the establishment of "pilot plants," where new processes are developed on a commercial scale. This general idea is now being successfully applied in other types of industries and can be expected to accelerate technical progress and developments in the future.

Very careful consideration and good business judgment must be exercised in the selection of new projects to be reasonably certain that they have sufficient merit and commercial possibilities even to justify carrying through an incubation stage. Here management has a difficult and somewhat paradoxical problem of not being overpersuaded by the enthusiasm of the inventor and at the same time maintaining the enthusiasm of the research personnel when their projects, in which they are personally interested, are turned down for lack of economic or commercial value. While the maintenance of an optimistic point of view is desirable, business cannot ignore economic considerations. The morale of the research group can usually be maintained in such cases by a frank discussion of the reasons for the decision. It should be realized that in spite of careful selection and accelerated progress, unprofitable operation on new products for prolonged periods is the rule which in turn increases the risk industry must continually assume and is a fact which is not generally appreciated by the public.

Commercial Development

In the final analysis, the climax to all industrial research and development work is the purchase and use of a new product by the ultimate consumer. It is therefore essential to study the consumer's needs and desires as a guide in the development of new products and to follow his reactions to newly developed products to determine their acceptance. The increasing importance of this viewpoint has been recognized and market analyses and studies of the trends of consumers' needs and desires are being reflected back down the line in such a way that they have a large influence on commercial development.

In large industrial organizations, commercial development work is usually conducted outside the research group and by the operating divisions who are responsible for the design, manufacture, and sale of various lines of established products. This work is largely directed toward the elimination of minor troubles and the application of improvements in performance reliability, appearance, etc., so as to increase the public appeal and acceptance of a product. It involves the study of material processes and standardization, manufacturing methods and procedures, tool equipment and production methods, and cost reductions of all kinds. Although this kind of work has a very definite and specific objective, it often brings out limitations and lack of knowledge and information which lead to research work of the types described above.

Influence of Patents

A discussion of the subject of technical progress would hardly be complete without emphasizing the important influence of the patent system, particularly at this time when there seems to be so much agitation in some circles to place limitations on private research and patent rights. It has been stated that "no fewer than 15 bills to prohibit the patenting of labor-saving machinery or improvements thereof have been introduced during the present Congress." A great deal of our technical progress in America can be credited to our patent system, and any action to limit its protection would indeed be regrettable. It costs money to develop and exploit inventions. The protection afforded by patent claims provides incentive to develop new things and under such conditions they may be exploited for a long enough time to become established. Without such protection, capital could not afford to venture into new fields, and industrial research would become very secretive, and because of the resulting lack of co-operation, our great advances in living standards and human comfort would be seriously handicapped. Let us be determined to support and encourage individual and private initiative rather than curb it, so long as it is based on sound economic foundations. Scientific advances based on economic improvements are inevitable. Economic laws and human nature cannot be effectively legislated against.

Attitude of Management Important

In this discussion, development activities and functions have been broken down to some extent in an effort to

clarify and illustrate methods of control and supervision, but it is recognized that close co-operation and co-ordination of all phases of the work are essential to successful operation. Francis Bacon recognized the importance of organized research as far back as 1620, when he said:

> If many useful discoveries have been made by accident or upon occasion when men were not seeking for them but were busy about other things, no one can doubt but that when they apply themselves to seek and make this their business, and that, too, by method and in order and not by desultory impulses, they will discover far more.

It is almost axiomatic that technical progress is dependent entirely on progress or accomplishments in research and development work in the various branches of science, and unlimited illustrations could be supplied to substantiate this claim. It therefore appears that the greatest responsibility—or probably we should say opportunity—of management in maintaining technical progress is to accelerate research and development work through better administration and control of organizations engaged in this kind of work. In addition to a more rigid application of the usual principles of efficiency and economy of operation, a sympathetic and encouraging attitude on the part of the top management of a company is considered essential. This promotes co-operation and teamwork among the personnel of research groups and is conducive to good performance, which, after all, is a large factor in the determination of the rate of our future progress.

No invention or development is an unmixed good even though it may be based on sound economic principles. As inventions enlarge our activities and broaden our lives in one direction, they cause shrinkage and distress in another. It is the gradual but positive net progress over a long period of time which counts and we must not become disturbed and thrown from our long-range course by temporary upsets in our social and economic progress. Any basically new idea is really beyond our comprehension and vision. If we could visualize it, it would be immediately developed. However, we may be sure that engineers and scientists will continue to make new discoveries—new ways to heal and save, new ways to kill and destroy; and out of it all we will have new joys and new sorrows along the road of progress to better standards of living.

Amplitudes of Magnetomotive-Force Harmonics for Fractional Slot Windings

FRACTIONAL slot windings have certain well-known attributes which cause them to be quite generally used in synchronous machine design. However, a winding occasionally will be produced which will develop harmonics in the air-gap magnetomotive force that will lead to excessive losses, vibration, and noise. The purpose of this paper* is to develop general formulas for computing the distribution factor and pitch factor of any magnetomotive-force harmonic set up by three-phase fractional slot windings of normal design, in order that a winding arrangement may be chosen that will minimize ill effects. The formulas are said to be sufficiently simple to permit a complete tabulation of distribution and pitch factors over the normal range of slots per phase per pole now used in fractional slot windings.

*Abstract of 1938 AIEE summer convention paper number 38-53, by J. F. Calvert (A'27, M'35) which will be published in full in TRANSACTIONS.

Reactance of Square Tubular Bus Bars

SQUARE tubular bus bars are being used to an increasing extent,as they are economical and convenient for joining to insulators and to branch circuits. The reactance of busbar circuits frequently is of importance, in order that the voltage drop under normal conditions and the current under short-circuit conditions may be computed. The purpose of this paper* is to present formulas and curves by which the reactance of square tubular bus bars may be determined.

Curves are given showing the reactance of thin square tubes, assuming uniform distribution of current, and the approximate corrections for rounded corners and thick walls. Illustrative examples show practical use of the method of computation.

The reactive drop in each conductor of a group of parallel conductors may be expressed in terms of single-phase reactances by first expressing them in terms of self- and mutual inductances and then arranging them in pairs. An example for a three-phase bus bar is given.

Selection and Design of the Electrification of the San Francisco-Oakland Bay Bridge Railway

THREE railway companies will operate electric trains over the San Francisco-Oakland Bay Bridge, using a dual-voltage system that supplies 600 volts from a third rail and 1,200 volts from an overhead conductor. Reasons for the selection of this system and the plan of the electrification are given in this paper.†

Mercury arc rectifiers provide direct current for the electrification from three substations, two of which supply both the 600- and 1,200-volt systems while the third supplies the 600-volt system only. The running and guard rails, which are used for the return current, are bonded carefully to prevent leakage of current to the bridge structure. Special problems were met at expansion joints because of the extraordinary length of the bridge, the movement amounting to four feet per joint in some instances.

* Abstract of 1938 AIEE summer convention paper number 38-79, by H. B. Dwight (A'11, F'26) and T. K. Wang, which will be published in full in TRANSACTIONS.

† Abstract of 1938 AIEE Pacific Coast convention paper number 38-99, by W. P. Monroe (A'19, M'26) which will be published in full in TRANSACTIONS.

Chemistry and High-Voltage Dielectrics

By F. M. CLARK
ASSOCIATE AIEE

Development of high-voltage dielectrics to meet the increasingly exacting demands of modern applications challenges chemical ingenuity and constitutes the broad avenue of chemical approach to the problem of high-voltage engineering

THE PROBLEM of the high-voltage dielectric can be approached from the physical or chemical standpoint, although the traditional approach is along the pathway of physics and engineering. The insulating properties have been considered as largely inherent and fixed. The object has been to determine their variation with changing environment. Such attempts as have been made to "lift the cover" have been carried out chiefly by students of molecular structure interested in a study of the fundamental nature of matter. This method of physical attack has been successful in that it has been able to classify and apply materials commercially on the basis of their "normal" dielectric properties. Since some of the most common commercial insulating materials, such as mineral oil and paper, are good insulators, the physical method of attack perhaps has been the one heretofore best adapted to produce the most rapid progress within established electrical demands. The more stringent requirements of the present time, however, cannot be met even by an unceasing search for standardized products. The properties of dielectrics must be considered as living, not dead—as flexible and controllable. Voltage and heat, ever present factors in the use of modern high-voltage insulation, must be looked upon as reagents of reaction, the course and speed of which is variable in accordance with the recognized laws of chemical change. Dielectric-test results must be considered not as a fixed and immutable goal but as tools to a chemical answer. Dielectric defects revealed by physical tests on existing materials are not to be considered as warning signs indicating the end of the road. The pathway of dielectric progress is not a dead-end street. Dielectric defects must be considered only as detour signals clearly legible when expressed in terms of chemical behavior. The marked progress of industrial chemistry during the past several decades has been made on the recognition that naturally occurring products are not necessarily the ultimate in perfection. Studies of the chemical requirements demanded and the synthesis of improved materials invariably have marked the line of progress. Mineral oil and cellulosic insulations are no exception. Important as these products have been in the history of electrical insulation, materials better adapted for high-voltage insulation are possible. The development of such products challenges chemical ingenuity and constitutes the broad avenue of chemical approach to this phase of engineering progress.

Prepared especially for ELECTRICAL ENGINEERING, based upon an address delivered at a conference on insulation held September 8, 1938, at Milwaukee, Wis., under joint auspices of the American Chemical Society and the chemistry subcommittee of the National Research Council committee on electrical insulation.

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Dielectric Strength

When one considers high-voltage dielectric practice, if one approaches the problem in the traditional manner, one turns at once to the property of dielectric strength. Questions relating to its vagaries at once arise. What is the effect of temperature? How does the strength change with thickness? If one follows such an attack, one determines the response of the dielectric to changes in environment and ultimately develops empirical mathematical relationships clearly describing the material under study, but yielding little or no information concerning how materials can be developed that are better adapted for the use at hand. Such an attack leads to a description of dielectric behavior as is included in the so-called pyroelectric theory of dielectric breakdown. Insulation fails because of heat accumulation. Of course it does, but such a statement is superficial. Where does the heat come from? Why does heat accumulate, assuming proper engineering design? I have asked that question of engineers and physicists and have universally received the same answer—"from changes in the electrical-loss characteristics of the insulation." The step from this explanation to the chemical attack on the problem is obvious and presents what the author has chosen to consider as the first chemical approach to the problem of high-voltage dielectrics. If changes in loss occur, they must be due to some fundamental change in the material itself.

The physical investigator says that changes in electrical losses come from changes in the material resulting from the applied-voltage stress, oxidation, heat, or other factors, all of which are classified by the chemist as "reagents of reaction." There is the opening for the chemist. Dielectric breakdown in service is due to a deteriorating chemical reaction initiated and accelerated by the conditions of service imposed. Breakdown of insulation is fundamentally chemical, not physical. The

physical manifestation of breakdown only follows the deterioration produced by chemical changes. The passage of the arc is the culmination of the whole previous chemical history of the material.

Physical studies of the dielectric strength are usually tests for accidental contamination. In dielectric liquids, the test is often merely a means of detecting suspended particles and water. In the solid dielectric, it is frequently a test detecting conducting particles. In several instances the author has said that all organic materials are characterized by good dielectric strength when pure. The practical problem is usually that of purification. This offers a second avenue of chemical approach, for the chemist, of all scientists, is best trained for the solution of such problems. His knowledge of chemical stability and chemical behavior is invaluable in the development and application of improved purification processes.

However, all insulating materials, when pure, cannot be said to be characterized by good dielectric strength, without some reservations. Not all materials have equal dielectric strength although all materials may have good dielectric strength when pure. For example, if one tests the dielectric strength of mineral oil as commercially prepared and water free, the normal dielectric strength is about 30 kv under the usual conditions of test. Under the same conditions of practical preparation and test, the dielectric strength of other liquid materials of similar viscosity may be from 30 to 100 per cent higher, depending on the actual conditions of test comparison. The liquid chlorinated hydrocarbons, for example, are characterized by a normal dielectric strength from 30 to 50 per cent higher than that of mineral oil. It may be suggested that this is merely evidence of a greater resistance of the chlorinated hydrocarbons to contamination, but in the gaseous state the chlorinated derivative also possesses a higher dielectric strength than the parent hydrocarbon. Yet even conceding that the increased dielectric strength of the chlorinated hydrocarbon liquid is due to a greater resistance to deteriorating influences, the result is the same. Materials are used under the ever present threat of contamination. That material which possesses the greatest resistance to deterioration of any type is the most practical. The conclusion is inescapable that from the dielectric-strength standpoint, naturally occurring products such as mineral oil are not characterized by the high value associated with synthetic hydrocarbon derivatives. The problem before the chemist is the proper selection and synthesis of these improved dielectric materials. The solution of the problem offers another chemical means of approach, but fundamental and basic research is needed before the goal will be reached.

Dielectric Stability

The property of initial dielectric strength, while fundamental in all lines of dielectric application, is not the only problem offering opportunity for chemical research. In fact, in most dielectric applications it almost might be stated to be the least important. Insulation rarely fails because of a defect in the initial dielectric strength. Careful chemical supervision of stock materials is an adequate protection against such troubles. Insulation in service usually fails because of deteriorating chemical changes arising under the conditions of service. These chemical changes result either in gas evolution, with consequent ionization effects, or merely in increased electrical losses which in turn cause dielectric failure through thermal disintegration of the dielectric—in other words, failure in accordance with the engineering concept of pyroelectric breakdown. The problem is directly manifested as one of dielectric strength. Fundamentally, the problem is one of chemical stability.

Chemical stability, at least in the author's opinion, is the most important property of any material used in engineering design. It is no less important in dielectric engineering than in the manufacture of rubber tires, lubricating oils, dyes, drugs, foods, and many other items, the instability of which has presented problems successfully solved by the chemist in the past. Many times the author has stated that the adaptability of a material for high-voltage-dielectric engineering can be gauged most accurately from a study of its chemical reactivity. Reactive materials are poor dielectrics for high-voltage engineering. This perhaps naturally follows from the molecular structure of the materials themselves. Reactivity and conductivity appear to be closely related to the polarity of the molecule. Marked polarity invariably is accompanied by marked reactivity and high electrical losses. Other factors such as viscosity being equal, marked polarity in molecular structure normally is accompanied by high solvent action and decreased resistance to electrical contamination by materials unavoidably present in electrical usage. The problem of the chemist is the synthesis of molecules capable of retaining their original identity against a variety of reactive reagents among which are heat, oxygen, and voltage stress. Given such characteristics, the other properties in most instances with which the author is acquainted are automatically obtained.

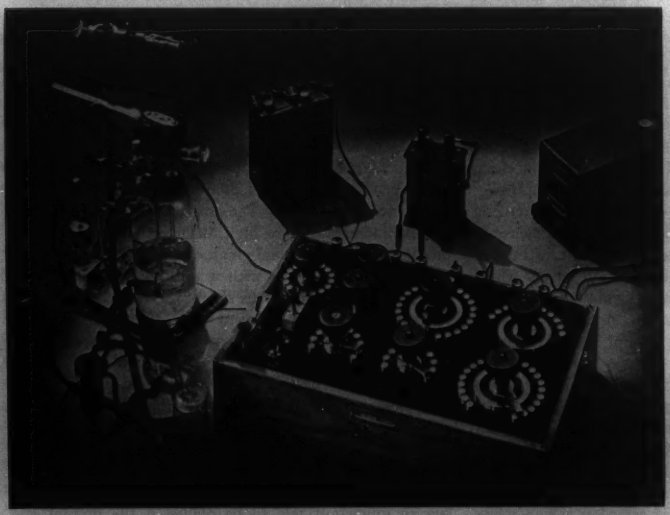
Of all organic chemists, the petroleum chemist perhaps has devoted the greatest amount of time and effort to the satisfactory solution of this problem. He has made marked improvements in his product in the past decade. In cables he has produced an electrically more stable product. In transformers, he has produced a product more free from sludging tendencies. Yet fundamentally he is fighting a losing battle if in the future he pursues the line of attack followed in the past. Refining experience to date has been based on the assumption, probably true, that mineral oil is a compromise product. Refining is a compromise between too little refining with attendant chemical instability of one type, and too much refining with attendant instability of another type. Such a product, once chemical research is aroused to the possibilities offered, cannot continue in use. Either the petroleum chemist must isolate and remove those materials the presence of which in mineral insulating oil constitutes the dangers comprised in the terms "overrefined oil" and "underrefined oil," or give way to the newer synthetic materials of improved stability.

But the problem of stability is only in its fundamentals a simple problem. Of course, the best material for high-voltage-dielectric engineering is that one which will retain its original identity under all conditions of use. It is inert under extreme voltage stress and extreme oxidation conditions. Such a material probably will not be immediately available. Perhaps the electrical industry will not suffer much if it is never available, for both fortunately and unfortunately such a product is not the only solution to the problem—fortunately, since such a product may never be found; unfortunately, since the questions arising from the possibility of using less stable materials without sacrifice are many and complicated. This is because high-voltage dielectrics are rarely, if ever, simple materials. Most dielectric problems involve at least two dielectric materials. In general, these are a mineral oil and the treated paper.

The fact that liquid and solid are used together raises questions of stability that can be answered only by the organic chemist. For example, two types of oil may be cited, each refined in accordance with similar technique but each with a different source of crude oil. Each, when chemically oxidized in a beaker, shows the same degree of electrical and chemical deterioration. Yet when tested in composite paper structure under the same conditions, one oil yields electrical stability and the other electrical instability to a degree that makes its commercial use doubtful and dangerous. Another oil will darken and increase more rapidly in acidic properties under oxidation than a second oil of similar characteristics, yet in turn will show increased electrical stability in the treated paper structure. What is the answer? The answer is obviously that the products of the chemical reactions and the dispersion of these products through the dielectric assembly determine the degree of resulting electrical instability. Yet who knows which products of mineral-oil oxidation are electrically innocuous and which are not? And who knows how to modify the present refining treatment of mineral oil in order to avoid the formation of electrically dangerous oxidation products? Comprehensive research in the chemical field alone can answer this question. The electrical tests are merely tools to a chemical answer.

Contamination Effects

The problem of stability cannot be solved merely by attention to the electrical changes observed in the material isolated from members of the assembly in which it may be a part. The problem is more complicated. Neither can the adaptability of a liquid, for example, be determined solely from its initial dielectric properties as compared with a standard. Our ideas of impregnating liquids of course are colored largely and unfortunately by our experience with mineral oil. Thus, from mineral-oil experience it often has been concluded that a dielectric impregnating liquid for high-voltage use must have a resistivity of at least 10^{14} ohm-centimeter at 100 degrees centigrade, and the higher the better! Yet experience shows that liquids with resistivities as low as 10^{11} or 10^{12} ohm-centimeter may be even better suited for electrical impregnating use. It is the chemistry underlying the actual electrical properties that is important. Each liquid material from the practical standpoint has a normal level of electrical resistance or a-c loss above which it can be maintained only with difficulty and below which only the presence of highly active, conducting contamination can cause it to go. For mineral oil, this normal value may well be 10^{14} ohm-centimeter. In general, the contamination that would lower the resistance of mineral oil to 10^{10} or 10^{11} ohm-centimeter is of the chemical type which would render the oil unsuited for electrical impregnating applications, not because of the lower electrical resistance, but rather because of the chemical character of the contamination per se. Yet a second liquid of normal resistance in the range of 10^{10} to 10^{11}



Some of the apparatus used to make electrical measurements that are valuable tools in the chemical development and control of dielectric materials

ohm-centimeter may be better than the first, even in its highest degree of electrical resistivity and loss properties. It is the chemistry and the chemical reactivity of the contamination that is important, not the simple electrical value in itself. Studies in this field having the object of isolating those substances that threaten the stability of liquid-treated insulation offer another fertile field for the research chemist.

The Oxidation Inhibitor

When a chemist finds that a certain type of molecule is objectionable, he invariably attempts to synthesize a product the structure of which eliminates these defects. However, another method of attack is the synthesis of a stabilizing agent. The commercial importance of stabilizing agents, retarders or antioxidants is indisputable. Because of the dielectric demand, however, the problems involved in the use of stabilizing agents in electrical insulations, are somewhat more complicated than in many other applications.

Oxidation is without doubt one of the major chemical problems facing the dielectric engineer. If oxidation could be eliminated completely, many of the problems of dielectrics would be simplified. In some instances it seems that the complete elimination of air in oil-filled apparatus can be guaranteed, yet the oil shows oxidation. What is the source of the oxygen? Can it be obtained from the cellulose molecule under high-voltage stress? Some evidence indicates that it may be so obtained. A cellulose chemist can offer the electrical industry real service by the elimination of this source of oxygen supply, if research shows that it does exist.

But assuming that the danger of oxidation cannot be removed either by the mechanical engineer with his design ingenuity or by the chemist with his synthesis efforts, there remains then only one way out—the use of oxidation inhibitors. While inhibitors have been developed for use in all sorts of things from foods to rubber tires and lubricating oil, the adoption of such products in electrical oils has been slow. The retarder itself must be studied not only from the standpoint of its efficiency in blocking oxidation, but also from the standpoint of its own dielectric stability. Small amounts of material dissolved in mineral oil, for example, can seriously affect the dielectric characteristics of the oil and, more important, of the oil-treated dielectric irrespective of oxidation effects which may be reduced or eliminated. Oxidation inhibitors therefore, even when used in small amounts, cannot be considered satisfactory without careful consideration of the dielectric results produced by the presence of the inhibitor initially and the effect produced by products arising from the chemical changes in the inhibitor under voltage, heat, and oxidation. Progress in this field cannot be aided by the blind adoption of an inhibitor just because the material has given excellent service in the rubber-tire industry. Careful research and dielectric investigation are needed to remove the fear of retarders which many dielectric engineers have at present simply because they have not been able to substantiate in the electrical field many of the recommendations ill-advisedly and thoughtlessly made to them, based on the behavior of the same inhibitor in other applications. The development of a satisfactory inhibitor for use in oxidizable insulating compositions presents to the chemist another important means of approach in his attack on the problems of an improved high-voltage dielectric.

Dielectric Constant

There is one property of insulating materials that is sold as such by the electrical industry. This property is the dielectric constant. It is sold substantially unchanged to the trade in the form of an electrical capacitor. The problems of stability, electrical losses, and electrical breakdown must be solved if efficient electrical service is to be obtained. These problems apply to all types of electrical apparatus containing insulation operating under high voltage. They apply with equal and perhaps greater force to the electrical capacitor which operates at as high, if not higher, voltage stress than any other electrical apparatus. Fundamentally, however, the electrical capacitor sells the dielectric constant. And the dielectric constant is one of the fundamental properties of the chemical molecule that the chemist can change at will. Starting from the parent molecule he can produce changes in dielectric constant simply by group substitution reactions. It is true also that he produces simultaneously a wide range of chemical reactivity and flammability, electrical losses, and stability, but the fact remains that he alone knows how to change the fundamental nature and properties of the molecule at will. He should be anxious to accept the challenge presented by the capacitor—to produce a high-dielectric-constant solid or liquid impregnating material suitable from the standpoint of other properties for use in electrical capacitors.

Not many years ago mineral oil was considered the only material suited to meet these stability requirements demanded by capacitor use. But mineral oil possesses a low dielectric constant. Today mineral oil has been largely replaced in the high-voltage field. The synthetic chemist has produced an improved product, chlorinated diphenyl. This synthetic liquid has many of the ideal properties so urgently demanded. The product is stable, nonoxidizing, noninflammable, of high dielectric strength, and reproducible with the usual greater reliability of a synthetic product in comparison with a natural product such as mineral oil. Physically the size of the capacitor has been reduced at least 50 per cent from the dimensions per kilovolt-ampere formerly associated with the use of mineral oil. Progress is being made, but the problem is not solved. The surface has only been scratched, and this single example of what has been done by the chemist has been cited in the hope that its accomplishment may stimulate increased interest on the part of the chemical profession and result in a closer union of the engineer, the physicist, and the chemist, each of whom has an important role to be played if the present and future problems of dielectric engineering are to be successfully solved.

Lightning to the Empire State Building

By K. B. McEACHRON
FELLOW AIEE

Combined photographic-oscillographic studies of lightning strokes to the 1,250-foot Empire State Building in New York City during the past several seasons, have confirmed some previous ideas pertaining to the nature and mechanism of the lightning discharge and have provided additional information enabling a more complete picture of this phenomenon to be drawn.

IN THE PROBLEM of protecting electrical apparatus from lightning, not only should the magnitude of the current and frequency of occurrence be known, but, of equal importance is a knowledge of possible wave shapes—how fast is the front in terms of amperes per microsecond, how slow can it be, and how long does the current persist? In the case of the multiple stroke, are the succeeding wave shapes like the first one, or how may they differ?

In an effort to throw additional light on these and other questions pertaining to the mechanism of the lightning discharge, a combined photographic and oscillographic study of the lightning strokes to the Empire State Building in New York, N. Y., has been made during the past four summers. Photographs of the strokes were taken with a variety of Boys (moving-lens or moving-film) cameras, while the cathode-ray and crater-lamp oscillographs furnished information pertaining to wave shape.

No effort will be made to make a complete summary of the results of this work, but some of the most important findings are as follows:

1. Oscillograms, or moving-film Boys-camera photographs, or both, have been taken of 55 strokes to the Empire State Building.

2. Direct-current arcs, with or without superimposed current peaks, extending between the cloud and the building continuing as long as 0.4 second, have been measured. These have been called continuing strokes.

3. Upward leaders from the building that developed into continuing strokes have been photographed, and data as to velocity of propagation secured. (Upward leader velocities range between 0.17 and 2.09 feet per microsecond with an average of 0.84 feet per microsecond.)

4. Currents measured during build-up of upward stepped leaders range from 50 to 650 amperes.

5. Branching was found to be in the direction of propagation of initial leader strokes.

6. At least 50 per cent of the strokes had a charge of 35 coulombs or more with a maximum of 164 coulombs. These values are several times as large as heretofore believed probable.

7. All strokes to the building began with the cloud negative. Three strokes changed to positive at or near the end of the stroke. About three per cent of the total charge measured was associated with the positive portion of the strokes.

8. Downward stepped leaders to the building were observed in one stroke only which had a velocity of 14 feet per microsecond. A stroke to a building 200 feet in height had a downward-stepped-leader velocity of 5 feet per microsecond.

9. Leaders on all discharges after the first always were downward whenever found, whether the initial leader was upward or downward. Such downward leaders had velocities ranging from 1.9 to 128 feet per microsecond with an average of 39 feet per microsecond.

10. Return-stroke velocities following initial stepped downward leaders were 340 and 150 feet per microsecond in the two cases recorded, while the returnstroke velocities following continuous leaders ranged from 98 to 280 feet per microsecond with an average of 197 feet per microsecond.

11. Every stroke but two of which the author has record, either struck the highest point on the building or outside a cone the base radius of which at the ground level of the building was equal to the building height.

Empire State Building

The Empire State Building in New York City is a steel-frame building surmounted by a metal tower, the top of which is 1,250 feet above the street. Extending above the top is an antenna system of the National Broadcasting Company used for television experiments. The antenna system in use during most of the investigation is shown in figure 1, but some of the earlier work was done with an antenna system of a somewhat different design. Approximately in the center is an antenna that extends above the triangular system and terminates at a point 38 feet above the top of the building. At a point 11.6 feet downward, the $1^1/_2$-inch duraluminum rod enters a 5-inch (inside diameter) brass pipe, being spaced from the pipe by suitable insulator.

During the taking of all the oscillograms discussed in this article, the inner conductor and outer pipe terminated at a point about 11.3 feet below the roof in a noninductive shunt having a resistance of 0.03 ohm, which is a part of the shunt used with the cathode-ray and crater-lamp oscillographs.

Prepared especially for ELECTRICAL ENGINEERING, based upon material presented in addresses to various AIEE Sections; a more detailed treatise on these studies is scheduled for publication in an early issue of the *Journal* of the Franklin Institute.

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The author and his associates wish to express appreciation to the National Broadcasting Company and the NBC engineers, particularly R. M. Morris and T. J. Buzalski, for making it possible to take measurements of lightning currents through the antenna, and allotting space in the top of the building for the oscillographs. Fletcher and Ellis kindly made available space in their offices in the building at 500 Fifth Avenue for housing the photographic equipment. Thanks also are due to Mr. Neave of the same organization for his fine co-operation. The author wishes especially to call attention to the part played by R. M. Partington, F. B. Headley, and A. C. Sugden, who successively operated the equipment during the three summers. The assistance of Mrs. Sugden during the 1937 season also should be mentioned. J. H. Hagenguth and C. J. Kettler deserve special mention because of their assistance in designing and building the equipment used. John Russ has been of much help in assisting in the preparation of this article. J. B. Bassett and other associates deserve the author's sincere thanks for their kind assistance in connection with this investigation.

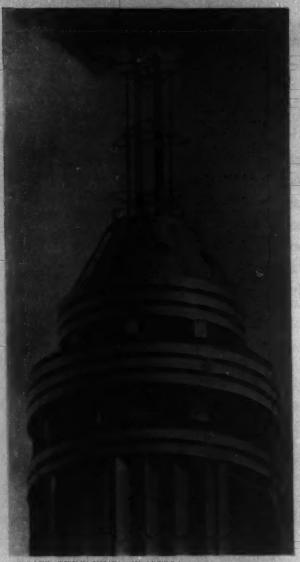


Figure 1. Antenna system atop Empire State Building, completed in this form July 1936; oscillographs connected to highest antenna

Photo courtesy *electronics*

At the insulator where the inside conductor emerges from the outer pipe, the smallest arcing distance is 1.25 inches. Obviously, for some strokes of lightning flashover will take place at the insulator, and therefore will interfere with the taking of oscillograms.

Oscillographs

Since one of the objectives of this investigation was the determination of wave shape, the cathode-ray oscillograph was arranged to initiate on waves whose rate of current rise was 2,000 amperes per microsecond or faster with a crest current of 6,000 amperes or more. The cathode-ray oscillograph was designed to record, on a continuously moving film, single impulses up to 100 microseconds in duration, also any succeeding impulses of like duration where the time interval between successive discharges was at least 500 microseconds. Because of the relatively low flashover voltage of the antenna insulator, the most severe lightning strokes to the building could not be measured because of insulator flashover.

Toward the end of the 1935 season, an examination of some of the photographic results indicated that with many strokes possibly current was flowing for a relatively long time, and an oscillograph was installed designed to record continuously discharges persisting as long as one second. This oscillograph was an adaptation of the crater-lamp oscillograph[4] used in an earlier investigation, but some modifications were required since the oscillographs at the Empire State Building could be serviced only at the beginning or end of a storm. As used in New York, the crater-lamp oscillograph galvanometer was connected to the shunt in the antenna circuit at all times, the drum carrying the film being run at constant speed, so that it was necessary to supply the illumination for the optical system only when a stroke occurred. This was done through the use of a crater lamp as a light source with a suitable initiating circuit, so that recording began within 20 microseconds after initiation voltage on the shunt was reached. The film speed was such that 0.90 inch represented 0.01 second. This oscillograph was arranged so that once set in motion 14 oscillograms could be taken without attention on the part of the operator. Films from this oscillograph have been designated as slow-speed records.

The shunt used for both oscillographs consisted of the 0.03-ohm shunt already mentioned in parallel with a Thyrite shunt. Using this combination of a linear and a nonlinear resistance, currents as low as 20 amperes were indicated with the crater-lamp oscillograph with a maximum measured of 24,000 amperes. The cathode-ray oscillograph was set to record a minimum of approximately 1,000 amperes, and a maximum of 200,000 amperes.

With both oscillographs, means were provided for determining the time of the stroke, so that the results could be correlated with those obtained from the various cameras.

Magnetic Links

During 1935, magnetic links were arranged to record current flowing in the two vertical antennas which existed at that time. After the radiator shown in figure 1 was erected, the magnetic links were so placed that the current flowing in each of the seven grounded vertical pipes extending above the roof could be measured. Readings from these links would not be expected unless the insulator at the top of the pipe to which the oscillograph shunts were connected flashed over, assuming of course that the stroke made contact at the highest point above the tower, which it did in every case that was observed, save one, during the three years of study. This stroke made contact about 16 feet down from top of antenna. Although not every stroke was observed, data were obtained for the great majority. There is also a photograph by Gaty[15] that shows a discharge to a point some 60 feet from the highest point, which at the time was the north antenna of the two antennas then in use. However, the number of strokes to the building for which current measurements could not be made was very small indeed. Furthermore, there is no evidence that any stroke divided, one part contacting some other part of the building, although one stroke did first contact another much lower building, and later discharges in the same stroke made contact with the Empire State Building. Lacking evidence of sub-division, the currents measured can safely be assumed to be the total current in the stroke.

When considering magnetic-link measurements, it must be remembered that the results represent only the highest current,[16] if all the currents were of the same polarity. If the polarity reversed, either in the same discharge or between discharges, some measure of the reversal may be obtained if more than one link at different radial distances

is used. In all the Empire State installations, three links were used, giving a wider range of current values and helping to determine the true value when reversal took place.

Photographic Equipment

Naturally, during the three years that photographs have been taken, there has been considerable development of the various cameras used. No attempt will be made here to describe more than briefly these cameras and their development.

During the 1935 season, the cameras were located to the west of the Empire State Building in the Nelson Tower. A Boys camera (referred to here as a high-speed Boys) made by Ross in London, was loaned by A. L. Loomis of Tuxedo Park, N. Y., and used by Lloyd and McMorris[17] to obtain the first photographs of leader strokes reported in the United States. A schematic diagram showing the operation of this camera is given in figure 2; this indicates how the use of two matched lenses and prisms allows a displacement of the image in opposite directions on the rotating film. A comparison of these two images, knowing the film speed, the focal length of the lens, and the distance to the stroke, allows a determination to be made of the velocity of the continuous leaders and the main strokes. As a rule, the stepped leaders have a sufficiently slow over-all velocity, so that a fair determination can be made without the second image. Of course, comparison could be made with a still picture, but the resolution would not be as good.

This Boys camera was operated at a film speed of 145 feet per second. Since storm activity over the Empire State Building is usually rather brief, early in 1936 a new type of camera was designed and built which would allow seven exposures to be made while maintaining full film speed. This camera has the same optical system as that shown in figure 2. It was designed for film speeds up to 344 feet per second. During 1936 it was operated at approximately 218 feet per second, which was reduced for the 1937 season to 124 feet per second, since it was found that considerable data were being lost because of the decrease in exposure time of weak portions of the stroke. To incorporate the feature of changing exposure while the film was running, it was necessary to operate with a short focal length, and 1.38 inches was adopted. A variety of different films was tried, but so-called "supersensitive panchromatic" proved to be very satisfactory. For purposes of study, the image is greatly enlarged. With this camera are obtained the continuous-leader data and most of the stepped-leader data. Rates of propagation of the main stroke also are obtained from these so-called high-speed Boys-camera records.

To determine the sequence of multiple-stroke discharges, a slow-speed camera is necessary. For this purpose a camera was constructed using an 8- by 10-inch film holder with two matched lenses having a focal length of 3.07 inches, mounted in front—one lens centering on the center of the film, and the other revolving with a $2^7/_8$-inch radius around the center lens as an axis. During the 1935 and 1936 seasons, the center lens revolved on its own optical axis, but because of a slight distortion due to the center of revolution being slightly different from the optical axis, this camera and another similar one constructed for the 1937 season were arranged with the center lens stationary. During 1935 and 1936, this camera was operated at one revolution per second; but when it was found that an occasional multiple stroke persisted for more than one second, it was decided to operate two similar cameras—one at two revolutions per second and the other at one-half revolution per second. The two center photographs, being taken with matched lenses, could be put together to give a stereoscopic picture, since the cameras were on the same level and separated 14 inches.

Having two slow-speed cameras has proved to be very helpful in analyzing the data, the slower of the two giving better over-all data while the higher speed gives better resolution of individual discharges. Furthermore, having two cameras of the rotating-lens type makes it quite certain that for most strokes the image will be in a good position for resolution on one camera or the other.

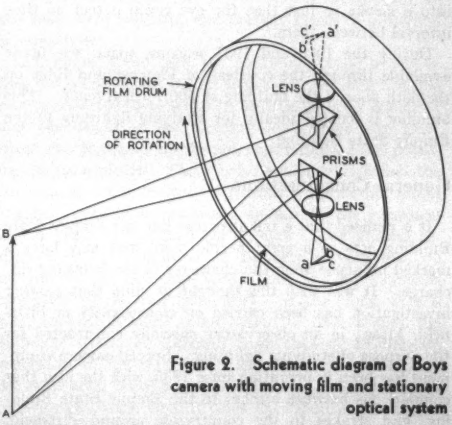


Figure 2. Schematic diagram of Boys camera with moving film and stationary optical system

Other equipment also was provided to make the mechanical work of taking the records as simple and foolproof as could be easily done. A Calculagraph was provided with which the time of operation and exposure of each camera was recorded in a manner similar to the timing of telephone toll messages. Each of the cameras had a printed form on which essential data, such as stop opening, kind of film, and other data pertinent to each camera, was recorded. The time of day and elapsed time, using the Calculagraph, was stamped on the same ticket.

An Ediphone also was provided for the recording of data, as the operator often was too busy to write down his observations. It was found, however, that the speaking tube restricted the operator too much as to freedom of motion, and during 1938 the operator used a lapel microphone, it only being necessary for him to change records, thus freeing him for other work.

Table I. Summary of Strokes by Years

Year	Storms	Strokes to Building	Oscillograms		Photographs With:			
			Day	Night	High-Speed Camera	Medium-Speed Camera**	Slow-Speed Camera*	Magnetic Link Records
1935	27	5					3	2
1936	26	22			5		16	2
1937	28	41	9	18	13	26	26	7

* One revolution per second in 1935–6, 1/2 revolution per second in 1937.
** Two revolutions per second in 1937.

Based upon the sound of corona and the discharges from one's fingers when standing on the small balcony near the top of the Empire State Building when storms were several miles away, it was thought that a stroke to the building could be anticipated if streamers from the building could be seen during storms at night. A careful watch was kept, and during the 1937 season the top of the building was observed through a 35-power telescope; but as was learned later, the corona streamer built up into a stroke so fast that the eye could detect no time interval between them.

During the 1936 and 1937 seasons, space was made available through the courtesy of Fletcher and Ellis, on the 56th floor of the building at 500 Fifth Avenue. This building is located ideally for studying lightning to the Empire State Building.

General Considerations

It is realized that a tall structure like the Empire State Building acts as a great needle point and may have a marked influence upon the character of the lightning discharge. It was with this thought in mind that another investigation has been carried on concurrently in Pittsfield, Mass., in an observatory specially constructed for the purpose of studying lightning. Special camera equipment has been in operation since 1935, with the idea that comparisons between strokes to the Empire State Building, and strokes to the countryside around Pittsfield, would make possible a better application of the New York data when considering transmission lines and other structures of similar height. The detailed results of the Pittsfield study cannot be given in this article, but the conclusions given here naturally will be colored to some degree by the results obtained there.

It is recognized that the photographic method has limitations as a light measuring means, particularly from the quantitative point of view. However, on all photographs taken in the last two years, each film has a sensitometer calibration, so that densities may be compared using a microdensitometer. Such an instrument is expected to be available soon for study of the records already made.

Results

During the three years of the investigation, the Empire State Building has been known to have been struck 68 times. Table I shows a summary of the strokes on which data were obtained. Nineteen oscillographic and photographic records were obtained simultaneously during 1937. No satisfactory records have been obtained with the cathode-ray oscillograph up to the end of the 1937 season.

Continuing Strokes

In 1935 three photographs were obtained of strokes to the building, and one of them also showed an interesting cloud-to-cloud stroke. In figure 3 is a stroke to the building showing several initial discharges followed by a period of varying but continuous illumination, with three rather considerable increases in intensity. This photograph led the author to believe that the continuing illumination was not due to effects following the initial stroke, but represented a more or less continuous current flow. Apparently Walter[18] had the same idea in 1905, but there was no direct proof, and apparently little credence has been given to this idea since Walter's suggestion. It seemed incredible that the illumination could persist so long after the initial discharge unless current was flowing, and that at times the intensity could be even greater than the initial discharge. From a study of these photographs, it was decided to install a crater-lamp oscillograph and measure, over at least one second of time, any current that might be flowing; and since the changes in current appeared for the most part to be rather slow, it was decided that the magnetic type of oscillograph would be suitable.

The results obtained in 1937, as illustrated by figure 4, show how beautifully the oscillograms and photographs

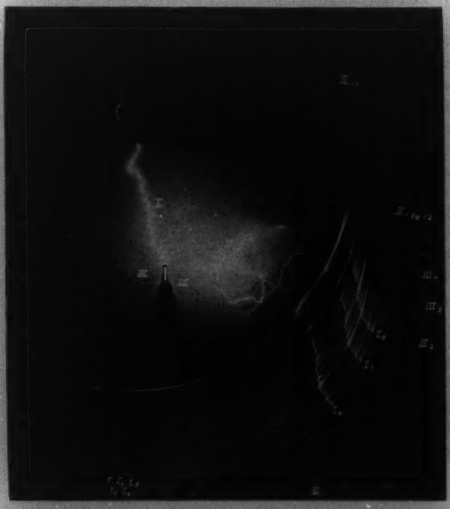


Figure 3. Stroke to Empire State Building and cloud-to-cloud discharges photographed with both still and rotating lens

I—Stroke to building. II and III—Cloud discharges

check. The same oscillogram is reproduced in figure 5, being drawn to a linear current scale. It may be noticed that each change in illumination is accompanied by a corresponding change in current. In general, where there is no illumination there is no current flow; but since the camera is 2,410 feet away, a slight degree of illumination would not be recorded. Furthermore, the oscillograph could not detect currents of less than 20 amperes. Laboratory tests with a long-time discharge from a high-current impulse generator show that the illumination, using the same Boys camera, does persist as long as the current flows, even for currents as small as 0.2 ampere.

This type of stroke, in which the current flows for a relatively long period of time, has been termed a continuing stroke. It may have superimposed upon it any number of current peaks.

When the current ceases entirely for a period of 0.02 second or more and a new discharge takes place through the same path, the stroke is referred to as being multiple. Of 47 strokes photographed on either or both the medium and slow-speed cameras, 34 indicated continuous current flow until the end of the stroke, 4 consisted of two succeeding continuous discharges in the same path with a time interval between, and 7 others began as continuing strokes followed by distinct discharges. No strokes were recorded that could be called multiple strokes alone, without some admixture of continuing discharges. One stroke was observed consisting of a single discharge that was not continuing. It is possible that all the strokes would have been found to be continuing if the equipment had been capable of detecting the effects of very small currents although this does not seem likely based on present data.

Figure 4. Multiple stroke to Empire State Building consisting of initial low-intensity long-continuing discharge and six subsequent discharges

The Boys-camera photograph was obtained from the building at 500 Fifth Avenue; oscillographic record below it was obtained in Empire State tower. Letters *A* to *K* mark corresponding points on photographic and oscillographic records

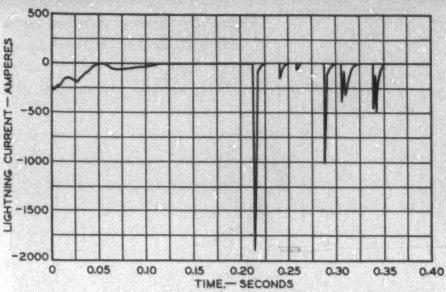


Figure 5. Replot of oscillogram of stroke shown in figure 4

These results indicate that the continuing discharge is really a d-c arc which may persist as long as 0.625 second and may have superimposed current peaks of a variety of magnitudes.

One might argue that the continuing type of stroke does not occur except to tall structures, yet once the discharge is started there seems to be little basis for assuming that the height of the building could have any great effect, except to shorten the arc, thus requiring less potential to maintain it. There is no evidence of which the author is aware to indicate that sufficient potential would not be available to maintain an arc of the increased length required to reach the ground. The ground resistance of the Empire State Building is very low, on account of the extensive foundations and pipe systems connected to its steel framework. If the cloud were a good conductor, there is no reason to believe that the discharge would be different from that of an impulse generator, to the degree that the discharge would obey the same laws, based upon the resistance, inductance, and capacitance of the circuit. But the cloud is not a continuous conductor; rather it consists of charges on drops of water separated by air gaps which must be broken down. Moreover, the cloud masses may be very large, and the charges in remote regions are not immediately available at the point of arc. The current peaks are perhaps the result of tapping new regions in the cloud separated or isolated by inhomogeneities of the cloud structure.

That the continuing type of discharge occurs to other than tall structures is evidenced by data from the Pittsfield lightning observatory, which shows many of the discharges to be of this type. Because of the relatively rather great distance of some of the strokes from the camera, continuing illumination in some cases could not be photographed even if present.

There is no doubt whatever in the mind of the author that continuing strokes are frequent to the open country, where the ground resistance may be either high or low, and that they also occur to transmission and distribution circuits where the ground resistance to d-c arc may be

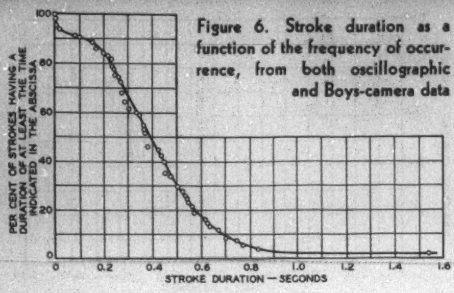


Figure 6. Stroke duration as a function of the frequency of occurrence, from both oscillographic and Boys-camera data

very low, as in a grounded-neutral system where the transformer winding represents a relatively small impedance to the flow of such unidirectional currents to ground.

Downward leaders, whether stepped or continuous, always are followed by a return discharge building up from the ground end through the established channel. With the upward stepped leaders no return stroke, as such, is found—the last streamer having extended itself to meet either a down-coming leader or streamer; current continues to flow in increased or decreased amount until the charges are so depleted that the discharge ceases. As a rule, the initial discharge of a continuing stroke is not very bright compared with discharges that may follow in the same path; however, in eight cases the photographs gave the impression of a strong upward main stroke at the beginning, but close analysis, often in conjunction with other data available, indicated that the apparent brightness was in the upward streamers—more likely the result of a succession of closely packed bright streamer tips.

Schonland, Malan, and Collens[11] suggested that the return-stroke process is dependent upon the availability of charge at the end of the leader channel, indicating that discharges into the air did not exhibit the return-stroke process because of a lack of charges at the end of the streamer. It would seem that the same explanation would account in part at least for the lack of return stroke process when a discharge proceeds from earth to cloud, that is, sufficient cloud charge is not immediately available to produce the return stroke.

Duration of Discharges in Same Path

The maximum duration of any stroke measured during the three years of study was 1.53 seconds, which is considerably longer than any reported heretofore. This time, of course, does not represent the longest possible duration, but considering all the data of this and other investigations it probably is close to the maximum. Using data from both the crater-lamp oscillograph and the Boys cameras, the curve in figure 6 was obtained. This shows that at least 50 per cent of the discharges will have a duration of about 0.4 second.

Polarity

Of the 55 strokes studied during the three years, none are known to be initially from a positive cloud center. All magnetic-link readings indicate negative cloud, although some reversal was obtained with many of the readings. It is best, however, to give most weight to the oscillographic records, since the information they yield is of a detailed nature, although the discharges of highest magnitude were not measured on the oscillograph. Those discharges that did not flash over the antenna insulator did not give magnetic-link records, but did give oscillographic records. For those cases where the oscillograph did not record, but the magnetic links did, it is safe to state that no stroke from a positive cloud occurred, unless it were of relatively small magnitude. It is believed that during 1937 such a stroke would have produced a record on the crater-lamp oscillograph, but since none was found there appears to have been no stroke initially positive to the building.

Of the 27 strokes for which oscillograms were obtained all but three were entirely negative, that is, from negative cloud. These oscillograms show how different in detail the lightning discharge may be, and considering the infinite variations of conditions in the cloud this does not seem strange.

One of the oscillograms showing reversal in polarity of discharge is reproduced in figure 8, which is for a continuing negative stroke (number 14) of small magnitude, followed 0.064 second later by a negative discharge having a crest of about 1,500 amperes. This was followed with almost exactly the same time interval by a positive dis-

Figure 7. Multiple stroke consisting of initial long-continuing low-current discharge and two heavier discharges, last of which had positive polarity. Rotating-lens image continued for more than one revolution

charge having a crest of about 2,000 amperes and persisting a little longer than 0.03 second. The entire stroke had few current peaks, but like the other two similar strokes recorded the reversal occurred at the end.

Photographs were obtained of stroke 14 with all three cameras, the medium-speed (2 revolutions per second) record being reproduced in figure 7. This shows the beginning of the stroke at the point marked, which by the way shows photographic reversal. The noncontinuing discharge at 0.314 second had a downward continuous leader having a velocity of 9.5 feet per microsecond (medium-speed camera). The position of the image of the third and final discharge, which was positive, was such as to make the determination of whether or not it possesses a leader rather difficult. At least none could be found in spite of the most careful examination of the original films. In no other regard was it possible to detect any difference that might be ascribed to change in polarity.

The third case of reversed polarity is that of stroke 21, for which the slow-speed (one-half revolution per second) record is shown in figure 9 with corresponding oscillogram in figure 10. As with the other two this stroke began as a continuing negative stroke, changing to positive at the end. The negative crest current was 600 amperes, while the positive was a little over 900 amperes. Such a stroke would have registered as a positive stroke on a magnetic link. No leader stroke was found at the point of change of polarity, although the variations in current and the corresponding changes in intensity for approximately 0.01 second after reversal may have some significance. This is discussed under the general heading of leader strokes.

No distinguishing characteristics could be found from the slow-speed record that would identify this portion of the stroke as being positive. If the illumination died out when passing through zero current, it is not apparent on the film.

Laboratory tests on a vertical 60-cycle arc with a current of approximately two amperes showed that the illumination in general dies out when the current passes through zero. It also was noted that the illumination is not continuous between the electrodes even though the current does flow continuously. This same phenomenon

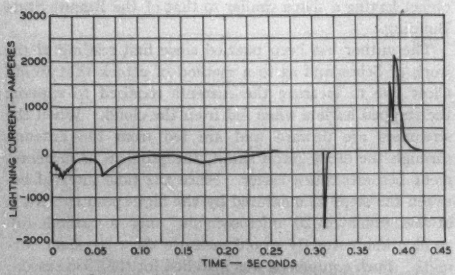


Figure 8. Replot of crater-lamp oscillogram of stroke shown in figure 7, showing reversal of polarity

Figure 9. Heavy single continuing discharge with large number of current peaks. Stroke reversed from negative to positive at 0.11 second

is apparent in the photographs of continuous strokes of natural lightning with moving lens.

Thus it appears that discharges to the building with positive cloud occur very rarely, if ever. Approximately 90 per cent of all discharges measured with the oscillograph were entirely negative. The other three strokes showing reversal began as continuing negative discharges, which seems to indicate that as the continuing discharge progressed, tapping more and more remote regions of the cloud, it finally reached an upper portion, perhaps where there was sufficient positive charges to give the results found.

Amount of Charge Transferred by the Stroke

Until these oscillographic results had been analyzed, the author[14] believed, based on the best information available, that 20 coulombs was the maximum to be expected from a single lightning stroke. However, one of the strokes recorded was found to have delivered a total charge of 164.1 coulombs, of which 2.6 coulombs resulted from the flow of positive current; this is about eight times the maximum previously estimated. Figure 11 gives the results in curve form for all the 27 strokes for which oscillograms are available. This curve indicates an expectancy of 35 coulombs or more for 50 per cent of the strokes.

Mechanism of Discharge

One of the most important contributions of this investigation to the study of lightning as a natural phenomena is the discovery in 1936 and measurement of upward leaders from the top of the building. (That upward leaders would be found was predicted by T. E. Allibone[21] in May 1938.) As a matter of fact, all the con-

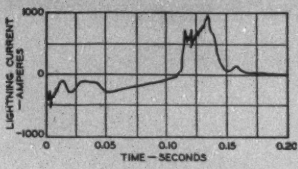


Figure 10. Replot of crater-lamp oscillogram of stroke shown in figure 9, showing reversal of polarity

tinuing strokes on which it is possible to make a good analysis show the existence of the upward stepped leader. It is nearly always visible on the slow- and medium-speed photographs when the beginning of the stroke is so located upon the film as to make analysis possible. It is difficult to measure propagation velocities on these slower-speed photographs, but over-all velocities can be obtained in many cases. The high-speed photographs also have shown some upward stepped leaders.

Seven strokes, which did not begin as continuing strokes and which had a rate of current rise steep enough to cause flashover of the antenna insulator, are all believed to have had downward initial leaders. Reliable data were obtained on 2 of these strokes.

There seems then to be two different types of strokes to the building, both negative in polarity: One is the continuing relatively low-current stroke beginning at the building and extending into the cloud; the other is like that identified by Schonland[10] where the stepped leader begins at the cloud, but this type of stroke to the building *for the cases observed* is not initially continuing and has a high rate of current rise, and presumably usually reaches a high current value before beginning to decay. Since downward and upward stepped leaders to the building, always with negative cloud polarity, have been observed, it would appear that the direction of propagation of the initial leader is not dependent upon polarity, but is dependent to a large degree upon the configuration of the two electrodes. Laboratory tests indicate that between needle and plane the discharge begins at the point, irrespective of polarity; this also has been checked by Matthias,[19] and Allibone.[21] Between two needles the discharge appears to start from each end, and this may be the case of the upward leader at the Empire State Building; but within the limit of our observation, which often extends as far as the stroke is visible, or at any rate 2,600 feet vertically, no evidence has been found of a downcoming stepped leader to meet the one coming up from the building. An intermediate condition may exist with conducting structures having heights of the order of 100 feet, such as transmission-line structures.

It is quite certain that branching takes place in the direction of propagation, and is not dependent upon polarity. This is confirmed by laboratory tests reported by Allibone and Meek[21] at reduced atmospheric pressure, as well as by unpublished work by the author. Allibone and Meek also found leaders from both electrodes when both were pointed. Most of the strokes to the Empire State Building that began with upward leaders do not show branching, but in five strokes branching upward was found. In those strokes where downward stepped leaders to the building were observed, no branching was found, although downward branching was found in strokes where stepped leaders were not recorded. In no case was downward branching found with upward stepped leaders or vice versa.

It was of much interest to find that all subsequent discharges following the initial discharge were preceded by a continuous downward leader in every stroke where a leader of any sort was found. Frequently leaders could not be found for subsequent discharges, but they may have been too weak to photograph. The fact that they are found on so many subsequent discharges would strongly indicate that they could be found on all subsequent discharges through the same path, if the limitations of recording permitted. Once the path was established, whether by upward or downward stepped leader, subsequent leaders always were downward.

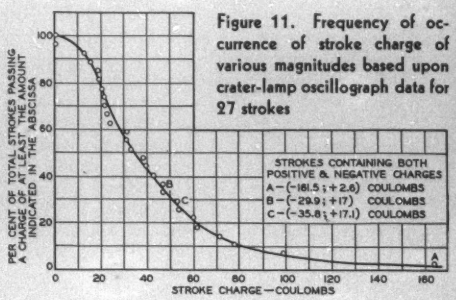


Figure 11. Frequency of occurrence of stroke charge of various magnitudes based upon crater-lamp oscillograph data for 27 strokes

The current in a continuing stroke need not reach zero in order that a discharge may occur with a continuous downward leader. One example of this kind was found, the continuing current being something less than 20 amperes when the sudden increase in current appeared. In general, downward leaders are associated with high rates of current rise, while with upward initial leaders the rate of rise is relatively slow.

In figure 12 diagrammatic sketches show the usual type of leaders to be expected, comparing a stroke to comparatively level earth with a stroke to a tall conducting object having a shape similar to that of the Empire State Building.

The author has been puzzled since first reading of the work of Schonland as to a method of attack that would allow one to measure the currents required to support the stepped leaders when fed from the cloud. When the streamers are upward and are fed from the antenna through the oscillograph shunt, the problem of measurement becomes much easier. Since the time interval between the steps as measured by the high-speed camera is of the order of 20 microseconds, only a cathode-ray oscillograph correctly would measure these streamer currents. Such equipment was installed for the 1938 season. However, the oscillograms do show a period of fluctuation during the streamer period which corresponds to a similar

fluctuation in illumination at the beginning of the continuing stroke. This type of disturbance is plainly visible in figure 13.

The first streamer currents are not recorded on the crater-lamp oscillograph, but if the period of fluctuation of illumination at the beginning of the continuing stroke indicates streamer currents feeding leaders within the cloud or out of range of the cameras, then the data indicates that these currents may be of the general order of 50 to 650 amperes. The first few streamers, those feeding the portion of the leader within the range of the cameras, appear to vary from 50 to 200 amperes. Considerable interest centers around what happens with a change in polarity, but no distinguishing difference could be found.

Leaders

Of 17 strokes photographed in 1936, 13 definitely are known to have been initiated by upward stepped leaders, while during the 1937 season, out of 36 strokes to the building 23 had upward stepped leaders. The remaining 4 strokes of the 1936 season could not be identified. All those identified as upward leaders were associated with a continuing stroke. Of the 13 strokes not having upward stepped leaders measured in 1937, 2 had initial upward continuous leaders and 2 had initial downward continuous leaders with 9 remaining without sufficient data to classify. Of these 9 strokes, 5 appeared only on the oscillograph record; and because the current was less than 125 amperes, initiation was delayed, so that if the characteristic current variation during the streamer period had been present it was lost. Three of the strokes occurred during heavy fog and were recorded on the slow-speed cameras very faintly. The ninth stroke was very weak and without discernible leader. Although all upward leaders initiated continuing strokes, and all continuing strokes for which leader data are available had upward leaders, either more data will show downward stepped leaders to the building initiating continuing strokes, or it will have to be concluded that this situation is peculiar to this tall structure. (This discussion is confined to strokes in which continuous discharge followed the initial stepped leader.)

Of the records obtained of upward initial stepped leaders, those for stroke 16 perhaps are most reproducible, and at the same time complete camera and oscillographic records are available. The medium-speed photograph reproduced in figure 13 shows the stroke beginning with an upward leader, the presence of which plainly can be seen on this record, followed by an illumination that gradually dies out. This is followed by six successive discharges. The oscillogram shown in figure 14 was delayed about 0.008 second in starting, due no doubt to the small current for initiation. The current after the leader had completed its path was small, being less than 100 amperes for 0.08 second. The last two discharges which apparently are each made up of two separate discharges, appear from the oscillogram to be one discharge. This also is confirmed by the high-speed photograph.

In figure 15 is reproduced enlarged sections of the film taken from the high-speed camera for stroke 16. In the upper record may be seen the initial upward stepped leader, with a velocity of propagation of 0.98 feet per microsecond, an average interval between steps of 30.4 microseconds, and an average length of step of 25.7 feet. Each of the bright points is connected with the top of the building with a streamer which is visible on the film in nearly every case, but may not appear after reproduction. Twenty-three steps are visible. The streamers move upward from the top of the tower at a velocity of approxi-

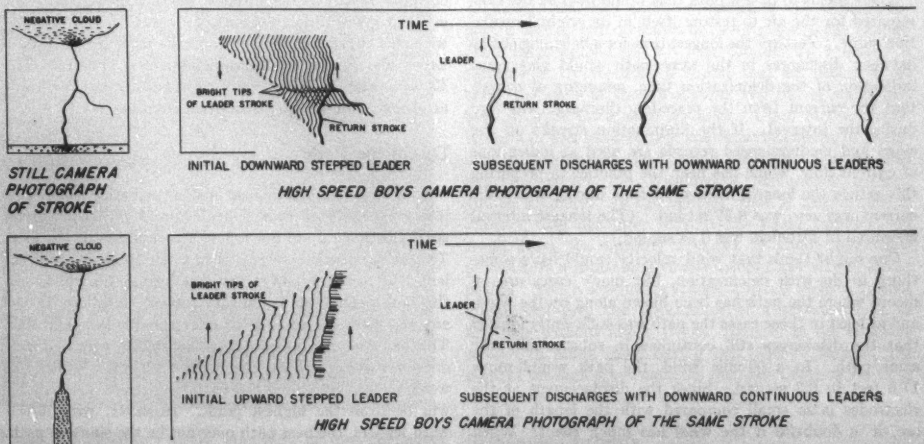


Figure 12. Schematic diagrams showing discharges from negative cloud to substantially flat terrain (upper) and to tall structures (lower). A few downward stepped leaders have been observed to the Empire State Building

mately 200 feet per microsecond. Almost all the streamers retard slightly as they approach the end of their travel, as evidenced by a change in slope of the streamer as drawn out along a time scale by the motion of the film.

No relation could be found between the length of step and the time interval. The minimum length of step was 19 feet and the maximum 69 feet. Most of the steps were close to the average of 25 feet, but considerable error can take place in this measurement, both on account of the smallness of the image and the variations of path in the line of sight. There is no proof that the steps are not substantially constant in length.

Although the time interval varied from 100 to 20 microseconds, most of the measurements were close to the average of 30 microseconds. The accuracy of these measurements is probably somewhat better than of those involving the length of step.

The six following discharges are reproduced in the lower portion of figure 13. Each has a continuous leader, the velocities of which were as follows in the order given: 16, 33, 50, 73, 45, and 44 feet per microsecond.

Upward-stepped-leader velocities ranged from 0.17 to 2.09 feet per microsecond while downward-continuous-leader velocities ranged from 1.9 to 128 feet per microsecond. Although an effort was made to determine if any relation existed between the amount of charge in a stroke and leader characteristics, none could be found with the data available. Likewise the time interval between succeeding discharges could not be related definitely to the velocity of propagation of downward leaders. More data may show some relation between these factors.

Deionization Time

There seems to be few data that would help fix the time required for the air to restore itself to its original insulation value. Perhaps the longest time for a lightning stroke between discharges in the same path would give some indication of the deionization time, assuming of course, that the current from the preceding discharge was zero during the interval. If the illumination streaks on the slow- and medium-speed records are used as indications of current flow, which has been the practice in preparing this article the longest interval of time during which the current was zero was 0.22 second. (The longest interval measured in Pittsfield was 0.44 second.)

One might think that wind velocity would have something to do with deionization, but many cases are on record where the path has been blown along by the wind, and at least in those cases the path was sufficiently ionized that the discharges still continued in substantially the same path. In a 60-mile wind, the path would move 17.6 feet in 0.2 second. Since the displacement at the electrodes is so small compared with the length of the arc, it is doubtful if the wind has much effect. When sufficient data are available, a relation may be found between the amount of current and its duration, which has an influence upon the time that the path remains ionized.

Branching

Although no statement can be made on data taken in the New York investigation concerning the effect of polarity on branching, yet with negative cloud, branching has been found both upward and downward, depending upon the direction of propagation. Six of the 27 photographed strokes to the Empire State Building secured in 1937, show branching, four being branched upward and two downward, with corresponding upward and downward initial leaders.

In general, the character of the downward branching is quite different from that of upward branching, appearing as rather short branches only a few hundred feet apart, measured along the main stroke channel. Frequently the upward branches reach out to cover a considerable area, although this is not certainly true in every case recorded. In the case of the path immediately adjacent, no division was recorded closer than 600 feet from the top of the building.

If direction of branching can be taken as an indication of the direction of propagation, in the many cases where still photographs are available but no moving-film records have been taken, considerable progress will have been made in the analysis of wave shapes of lightning current reaching transmission lines and similar structures, assuming that the rate of propagation and amount of charge determine the wave front and crest current.

Maximum Currents Measured

Table II shows the values of current measured with the magnetic links during the four years they have been in use.

In figure 16 is plotted the frequency of occurrence of currents of various magnitudes, whether measured by the oscillograph or through the use of magnetic links. Plotted with this curve is one taken from the most recent data of Lewis and Foust[2] for transmission lines, and from McEachron and McMorris[22] for currents through lightning arresters connected to distribution circuits.

Discharge Path

Since the electrostatic field is along smooth curved lines, it is very evident that lightning, and for that matter sparks in general, do not follow the direction of the field. This is because breakdown is not simultaneous over the length of the path, and the progressing streamer picks out the best path from instant to instant, resulting in the crooked path so familiar to one who studies lightning. This being so, it is not difficult to visualize why lightning does not always strike the highest object. Where upward leaders determine the path, the stroke presumably will be from the highest point. However, with downward leaders, the best path may not be the shortest path, and the attractiveness of one path over another may change even during the progress of a multiple stroke.

The first stroke of this type to the Empire State Building to be photographed is shown in figure 17 and was

taken in August 1936. Two strokes to the building appear in this record, the camera having been moved between them. Unfortunately at the time the stroke on the left occurred the moving lens had closed so no detailed record is available of what happened. However, the record from the still lens tells an interesting story. The path of the stroke is displaced sufficiently so that four discharges may be seen. The first discharge of the series struck a building 360 feet high and 1,200 feet west of the Empire State Building. Since this first discharge is branched downward, presumably in the light of present knowledge, it had a downward leader. The three following discharges left the path of the first discharge at a point 655 feet above the Empire State Building, the first discharge to reach that building showing at least one downward branch approximately 550 feet above the building. The remaining discharges had no branches that could be detected. It may be that a streamer built up from the Empire State Building which changed the course of the succeeding discharges, but there is no evidence to support this idea except that it is what one would expect.

Out of a total of 46 strokes recorded to the building, no stroke has terminated within a cone whose base radius on the ground is 1,200 feet, except one which terminated 16 feet down from the top of the antenna. The Gaty[18] photograph referred to in the beginning of this article is the only other known stroke that failed to strike the top and struck within the cone.

Figure 13. Multiple stroke consisting of long-continuing low-current discharge followed by six noncontinuing discharges. Arrow indicates point at which oscillograph started to record

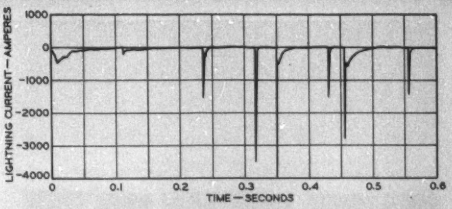


Figure 14. Replotted oscillogram of stroke shown in figures 13 and 15, showing seven discharges for each of which a leader was found

Upward Streamers Without Connecting Stroke

Two upward streamers from the Empire State Building that did not result in a stroke to the building were photographed in 1937. One of these was about 300 feet long, and apparently took place at the time of a cloud-to-cloud discharge. Details are lacking on account of the poor visibility at the time. The other streamer occurred at the time of a single cloud-to-cloud discharge when a branch downward came within 400 feet of the top of the building. The upward streamer from the building top extended to within 130 feet of the downward branch.

One upward streamer also was photographed in 1936 extending 85 feet upward from the Metropolitan Life Insurance Building which is a structure 657 feet high and situated 2,100 feet from the Empire State Building. The same film also shows a stroke with upward leader from the Empire State and one with an upward leader from the Cities Service Building.

Thunder

During 1935 the engineer operating the camera reported that on two occasions he saw strokes to the Empire State Building, but did not hear thunder as it usually is identified. He reported a sound that he described as being the same as though a paper bag full of water had been dropped for a short distance. Upon further investigation it was recalled that the Superintendent of Buildings in Washington, D. C., had reported[24] that in 1885 lightning struck the Washington Monument without audible thunder. In the light of what is known now, it appears that lightning without the usual thunder will result from the upward streamer of small magnitude followed by a continuing stroke without any steep current peaks. Such a continuing stroke, which is really a d-c arc, might well give the appearance of a severe stroke of lightning without much, if any, thunder in the ordinary sense. In many cases during the 1936–37 seasons, the noise of the high-speed cameras was such that observations on thunder were often unsatisfactory.

Streamer Currents

The velocities of upward stepped leaders fall within the limits measured by Schonland for downward stepped

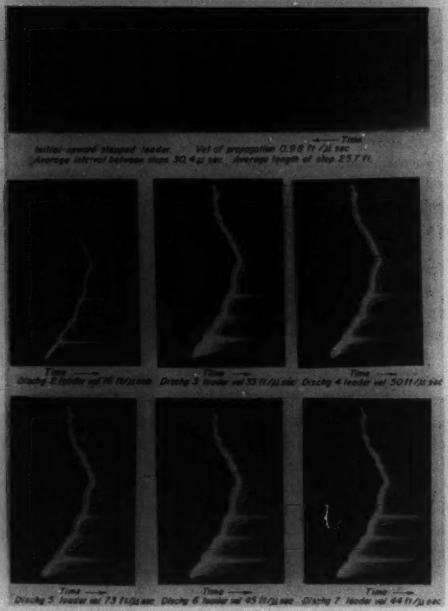


Figure 15. High-speed record of multiple stroke shown in figure 13

Top record shows progress of initial upward stepped leader. Lower records show six noncontinuing discharges, all with downward continuous leaders. Although all leaders showed plainly on the original negative, retouching was required to make them visible in the reproduction

leaders, and the time intervals are of the same general order of magnitude. The downward continuous leaders had velocities also within the limits obtained by Schonland and ourselves when measuring strokes to open country. These comparisons lead one to believe that as a first approximation the streamer currents from the top of the building will be of the same order of magnitude as those that move downward from the cloud in the stepped leader.

A consideration of the data seems to indicate that the stepped leader has about the same characteristics whether upward from a well-grounded building or downward from a cloud having charges residing upon the surface of drops of water or ice particles more or less insulated from each other. Since the lack of mobility of charges within the cloud will have but little effect upon the mobility of charges in the earth, it is reasonable to conclude that the mechanism of the stepped leader is not peculiar to the cloud and its formation, but would have existed if the cloud had been a conducting body with a point of concentration provided by a long conducting needle pointing toward the earth.

Considering the upward and downward leaders from another point of view, as seen from the earth end a downward leader attached to the cloud through a streamer starts an upward moving main stroke following contact with the earth. The velocity of the streamer is known, also the velocity of the returning main stroke. As viewed from the cloud end a time interval of several hundred microseconds would elapse before the main stroke reached the cloud. If conditions are the same for the upward leader one might expect a similar waiting time before the return of the main stroke, of at least half that time, if the leaders were both downward from the cloud and upward from the building. But no such time interval has been found, the last upward streamer merely becoming more intense and developing into the main stroke. What this means when applied to the downward stepped leader as viewed from the cloud end the author does not know; perhaps additional data will supply the answer.

A Picture of the Lightning Stroke

The picture of a lightning stroke as it appears to the author at present is something like the following: The majority of lightning discharges photographed in the past were branched downward, indicating downward leaders; this is to be expected when the earth is more or less a plane surface as regards the cloud, which due to its construction automatically begins to act as a needle point as the charges accumulate in some part of the cloud. The discharges proceed from the cloud in a series of steps, always being fed by a streamer from the original cloud. As this streamer progresses, choosing the best path, the charges upon the earth's surface begin to flow into the

Solid curve—Based upon 27 strokes to Empire State Building recorded by crater-lamp oscillograph and 11 magnetic-link readings

Dashed curve 1—Lewis and Foust data (reference 2) based upon 358 strokes to transmission lines

Dashed curve 2—McEachron and McMorris data (reference 22) based upon 1,608 discharges through distribution lightning arresters

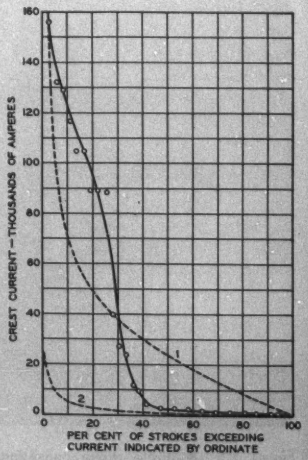


Figure 16. Frequency of occurrence of strokes of various current magnitudes as determined by three different investigations

region of increased field strength due to the approaching streamer. When the field strength becomes sufficient, streamers will form from grounded objects on the earth's surface. The stroke usually will contact the longest streamer; the return stroke follows, in which charges from the earth will pass up the stroke channel, their flow constituting the current in the discharge. The shape of the front of the wave will depend upon the rate at which charges flow into the point to be struck. The crest current will be determined by the number of charges flowing into the channel at the time of contact; and if the stroke is to be continuing, charges will continue to flow until the supply is exhausted in either the earth or the cloud.

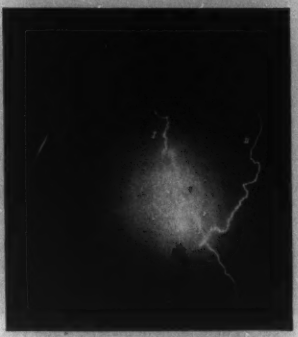
Thus the shape of the front of the wave of current of a lightning discharge with initial downward leader to a transmission line is probably dependent upon the amount of charge and the rate of its propagation toward the point to be struck, while the shape of the tail of the wave is dependent upon the amount of charge available. It is not known whether or not the percentage of continuing strokes to open country is as great as to the Empire State Building, but it is known that they do occur frequently and are probably dependent to a large degree upon the distribution of charge within the cloud for their existence. If it is true, as suggested, that the current in a discharge with a downward leader will be maximum (unless some new cloud charge is tapped) when that leader makes contact with either the earth or a short streamer from the earth, the magnitude of that current will be determined by the charge in the earth and its availability. The amount of charge in the earth will be related to the amount of charge in the cloud and so will the maximum current. A considerable portion of the charge associated with the particular stroke will move from the cloud down into the channel created by the leader. This channel of charges will extend all the way to the earth to unite with the charges from the earth when contact is made. This reasoning would lead one to believe that continuing strokes with downward leaders would be likely to have an initial peak followed by the more or less steady current flow due to the partial or complete discharge of the cloud center.

Presumably discharge starts from the cloud without being influenced much by the earth configuration, but as the discharge approaches it is influenced more and more, although as a rule that influence is local in character. However, the taller the conducting object, the greater its influence. With strokes initiated by upward leaders, the situation is different. It is believed that upward leaders will occur only when conditions on the earth simulate a needle point of sufficient height to have an influence on the propagation. Perhaps some natural configurations of the earth might be of such a nature as to produce the upward leader. However, it seems to the author safe to state that the downward leader stroke represents the type of stroke of greatest importance in the problem of protection of transmission lines and apparatus.

The effect of the continuing type of stroke must be determined. It does not seem to be of great importance on grounded neutral electrical systems, because the continuous current readily can flow to ground through the transformer windings. The isolated-neutral system may have trouble with protective apparatus connected to ground. Just how important this matter of continuing strokes will prove to be is not known at present, but it may help explain some of the failures of lightning arresters attributed to arcing grounds or other system disturbances. The continuing type of discharge may have considerable effect on the blowing of fuses used to protect distribution transformers when operating with grounded neutral.

The amount of charge involved in the continuing stroke gives some idea of the amount of charge in a cloud center. Assuming a crest current of 200,000 amperes and a time to half value of 50 microseconds, the charge would be but twenty coulombs, which is less than the average obtained in New York. However, this difference is to be noted: These large amounts of charge result from the relatively long times involved, which possibly suggests that only a part of this charge would be available for a high-current short-time discharge. All this indicates the extreme im-

(*Concluded on page 507*)



Stroke I consisted of at least four discharges; the first of the series struck a building 360 feet high and 1,200 feet west of the Empire State Building. Remaining discharges contacted Empire State Building

Figure 17. Two strokes (I and II) to the Empire State Building, the cameras having been moved between the two strokes

Table II. Maximum Currents Measured With Magnetic Links—Empire State Building, 1935 Through 1937

Date	Maximum Current (Amperes)	Number of Strokes Represented
June 27, 1935	− 27,500	1
July 19, 1935	− 40,000	2
August 23, 1936	−105,000	11
August 17, 1936	− 89,000	1
May 13, 1937	−156,000	
June 2, 1937	−117,600	
July 11, 1937	− 88,200	3
July 26, 1937	−129,500	8
August 11, 1937	− 89,600	19
August 18, 1937	−132,300	5
September 4, 1937	−105,000	6

NOTE: Current values indicated for 1936 and 1937 represent summation of all current values measured in the different parallel paths represented by the antenna structure on top of the building.

Value of the AIEE to Electrical Engineers

By JOHN C. PARKER
PRESIDENT AIEE

The greatest values of the Institute to its membership "are to be found, as elsewhere in life, through the opportunities offered for giving out rather than for taking in"

IT IS bromidic to say that the value of such an organization as the American Institute of Electrical Engineers to its membership is measured by the extent to which the member puts himself into the activities of the organization. There is, nonetheless, some value in the reiteration of these things that are well known.

It is true that the Institute sends monthly to the membership our professional magazine, ELECTRICAL ENGINEERING, which carries the news of the profession and a remarkable group of professional papers of the highest quality, and that the Institute makes available to its membership TRANSACTIONS which constitute an extraordinarily valuable reference library. If these publications merely find their way to the library shelves or into the wastepaper basket, they discharge perhaps a negative economic function. When used, they become a powerful instrument of that self-education which, in some form or other, any professional man must carry as long as he wills to grow in his profession.

Valuable as are these publications, I think they mark the least of the values of the Institute to its membership, the greatest of which are to be found, as elsewhere in life, through the opportunities offered for giving out rather than for taking in. The Institute will realize its fullest value to the membership when as many as possible of the 15,000 members are participating in some way or other in the conduct of their professional organization.

It would be difficult to stress too highly the value to those members who are creatively minded of preparing papers for presentation at the meetings of the Institute, large or small, formal or the most casual. The man who is doing things in his profession benefits much by organizing and appraising his own mental processes and presenting his ideas for the criticism of others. Those members who do not feel that they have as yet any major contributions to offer can still do a vitally creative thing in submitting written discussions.

In a larger and more generous way, this contribution to the technical proceedings of the Institute gives a man opportunity for growth in his profession which he cannot get merely out of the everyday performance of his own work, however good that may be.

In a narrower and more selfish sense, the floors of the Section meetings and the pages of the Institute publications give members an opportunity to make themselves known for what they are. I do not suggest that in professional advancement dressing the show window will take the place of solid merit, or that the returns from such participation in Institute activities will be immediate; but I do know that sound professional repute is based on just such opportunities for out-giving as the Institute offers.

Exclusive of duplications, 513 members of the Institute are engaged in the work of the general and technical committees of the national organization. I do not know how many hundreds are similarly engaged in the work of the Sections and Branches. Here again is an opportunity for the development and demonstration of administrative ability and of those personal qualities of co-operation that cannot but redound to the benefit of those men, particularly the younger ones, who show a capacity for selfless devotion to something bigger than immediate self-interest.

It is the hope and earnest intention of your officers that constructive means may be found whereby, in the various personal contacts offered by the Institute, the younger members may find opportunity to express themselves, and at the same time whereby the means may be created to bring the older members, even those in executive rather than in technical jobs, to the meetings of the Sections as well as to the major meetings. This at once should give the younger members an opportunity to know something of the kind of men who are building our profession and give these elders a chance to watch their successors perform. The mutual benefit of this is fairly obvious.

This much has to do with the narrower values that the individual engineer may, for himself, find in the Institute. There are other less tangible, but more real, values.

No man can hope to make a place for himself in society through the practice of a profession excepting as that profession takes a high and valued place in the social order. No profession can take a very large place in society except as the individual members make it strong and worthy of respect. Here in the Institute we have a great organization for mutual effort not only in promoting a better understanding and a fuller knowledge of engineering theory and practice, but of so directing that practice and giving it such a tone as will command more fully the respect of the world at large.

The Institute has been very jealous of its repute for a high quality in its publications and discussions, but even more for the highest of quality in its membership. I believe that that repute is a very real thing and that it has a wide acceptance. With the interchange of ideas and with the quiet expression of aspirations among a highly selected membership, the Institute can continue to do great things toward giving such social direction and emphasis to the work of the engineer as shall enable each of

An address presented at a meeting of the AIEE New York Section, October 19, 1938.

us to take an increasing pride and satisfaction in his professional associations.

This modern world is industrial to its core. The spring of industry is in the mind and in the spirit of the engineer. Whether an industrial civilization shall advance the human race or shall be a period of retrogression depends in no small measure on the ethical, the professional, may I say the spiritual, attitude of the engineer toward his work and toward the society in which he lives.

Here in the Institute, men of varied occupations in enterprises having to do with engineering find a common meeting place in which, incidentally to technical discussions and to administrative responsibilities for the conduct of the Institute, they may find opportunity to appraise, to stimulate, and to appropriate the highest visions of our profession and of its place in the slow and painful upward progress of mankind. This sort of co-operative effort is too subtle for legislative administration or for resounding resolutions. It may be even too delicate a thing for formal discussions, but I am sure that in the unconscious word dropped here or there in committee meetings, in the implicit sense of responsibility and obligation as it develops in board meetings, even in the fellowship of smokers and dinner-dances, all of us can find incentives to the highest of which we are capable—and deterrents from the lowest—through our daily work to do an honest job as electrical engineers devoted to the service of mankind.

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Lightning to the Empire State Building

(*Continued from page 505*)

portance of measuring the characteristics of the downleader type of stroke. Several of these occurred to the Empire State Building during 1937, but in all cases but perhaps one, flashover of the antenna insulator resulted.

It is also important to determine the streamer currents more accurately, which will be done in the future using a cathode-ray oscillograph instead of the magnetic oscillograph. It is also planned to attempt a correlation between the photographic intensity and the current in the stroke. If practicable, this would greatly extend the field of the observations.

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Basic Equations for Electric and Sound Radiation

THE purpose of this paper* is to derive the basic equations for electric radiation and for sound radiation by elementary calculus, without using the notions of differential equations or of vector analysis. The essential step is the selection of an elementary wave pulse discontinuous only at its front and not involving double layers nor regions of infinite energy at the wave front.

The procedure for electric radiation is to assume an elementary wave pulse having a certain current distribution; thence to find the distributions of magnetic intensity and electric intensity employing the law of magnetomotive force, the law that dielectric current is the time derivative of dielectric flux, and the proportionalities between the two intensities and their flux densities, as given by the proportionality factors for the medium; and finally to show that the remaining fundamental law, that of induced voltage, is everywhere satisfied.

The procedure for sound radiation in a gas is like that for electric radiation: to assume an elementary wave pulse having a certain distribution of rate of flow; thence to find the distributions of particle velocity and excess pressure, and finally to show that the remaining fundamental law, Newton's law, is everywhere satisfied.

* Abstract of 1938 AIEE summer convention paper number 38-92, by Alan Hazeltine (F'35), which will be published in full in Transactions.

News

Of Institute and Related Activities

Preliminary Plans Foretell Excellent Program for 1939 AIEE Winter Convention

TO PROVIDE interest for the greatest number of members a broad technical program of current interest and two general sessions have been proposed for the 1939 AIEE winter convention, which will be held in New York, N. Y., January 23–27, with headquarters in the Engineering Societies Building. Social events are being planned for the evenings—a smoker, presentation ceremonies for the Edison and John Fritz medals, and a dinner-dance. In addition, inspection trips will be arranged to a number of places of interest in the city and its environs. As in the past two years, an all-expense post-convention trip to Bermuda also is being planned.

One of the general sessions will deal with economic and social problems, which have proved to be of great interest to electrical engineers. Arrangements have been made for an address "Enterprise and Social Progress" to be given by Virgil Jordan, president, National Industrial Conference Board, Inc. Plans for the second general session have not been completed, but negotiations are under way for a speaker of national repute who will address the session on a subject of wide general interest.

Technical Sessions

As announced in the October issue, the technical program of the convention will include a symposium on rating and temperature limits of small power apparatus, which will be of outstanding interest to all manufacturers and designers of small motors as well as to those who furnish the insulating materials and to the users of the equipment. Tentative plans are that this symposium will embrace three sessions.

Other technical sessions that have been proposed embrace practically the whole gamut of Institute technical activities, as follows: electronics, protective devices, instruments and measurements, power generation, cable developments, power transmission, switching transients, communication, basic sciences, research, transportation, industrial power applications, and electric welding.

Further details pertaining to the program will be announced in the January 1939 issue.

Virgil Jordan, Noted Economist to Address General Session

By both training and experience, Doctor Virgil Jordan is eminently qualified to speak on the subject "Enterprise and Social Progress." A native (1892) of Olean, N. Y., he received the degree of bachelor of science from the College of the City of New York in 1912, and afterwards did postgraduate work in economics at the University of Wisconsin, Columbia University, and foreign universities. He taught economics at the University of Wisconsin from 1912 to 1914, and thereafter served as associate editor and special writer on economic and sociological subjects with *Everybody's Magazine* until 1920. From 1920 until 1929 he was chief economist and editor of publications of the National Industrial Conference Board, but

Virgil Jordan
A winter-convention speaker

in 1929 he became economist for the McGraw-Hill publications. In December 1932 he returned to the National Industrial Conference Board as president of that body, which position he still holds.

The National Industrial Conference Board is a private co-operative, non-profit scientific institution, devoted to promoting the property and security of the people of the United States by assisting in the effective operation and development of productive industry. Its function is to discover, assemble, analyze, interpret, and disseminate accurate, complete, and useful information regarding economic conditions in the United States and other countries.

Doctor Jordan has made numerous contributions to the literature of his specialty in popular and scientific periodicals, and in the publications of the Conference Board. He is a member of the American Economic Association and of the American Statistical Association, and a fellow of the Royal Economic Society of London, England.

Symposium on Apparatus Ratings of Far Reaching Importance

With the stipulated purpose of providing information upon which revisions in AIEE standards may be based, the symposium on ratings and temperature limits of small power apparatus is expected to be of far reaching importance to manufacturers and users of such equipment. Broadly, the purpose of the symposium is to review the fundamental properties of insulating materials on which AIEE standard temperature limits are based; to discuss improved means of measuring temperatures, enabling these limits to be complied with more exactly; and to discuss principles of rating for both continuous and intermittent loading conditions.

The origin of this discussion and of the need for revisions in the present standards lies chiefly in the rapid development of the refrigeration and air-conditioning industries during the past 10 years. In these industries, motors are used to drive compressors with automatic control which provides alternating on and off periods the relative duration of which varies with the temperature and the load requirements. The characteristics of compressors require certain ratios of starting, accelerating, and operating torques, which differ materially from the values specified in the standards for general-purpose motors. These differences together with the intermittent- rather than continuous-duty service, have led to operating loads and temperatures in excess of motor nameplate ratings. The need is evident on this basis for reconsideration of the motor-torque ratios in the present standards, and for provision of operating recommendations for standard motors used in intermittent-duty applications. Another important factor is the recent development of new insulating materials that may have different temperature endurance from that of materials provided for in the present standards.

Of the three sessions tentatively scheduled, it is proposed that the first deal with the temperature limits of insulating materials and include three formal papers. One of these would show test results taken over a period of from two to three years on the temperature-life characteristics of class *A* insulation. (Class *A* insulation consists of cotton, silk, paper, and similar organic materials impregnated or immersed in oil; also, enamel as applied to conductors.) The other two papers would deal with the

temperature and life characteristics of class *A* insulating materials under oil, and with the characteristics of fiber-glass insulation. Following discussion of these papers, the session would be resolved into an informal conference, and several prepared discussions are proposed on other phases of the subject. It is expected that in these informal discussions recent progress in synthetic varnishes and resins will be reported. Such materials not only play a large part in the determination of the permissible temperature for class *A* insulation, but also are limiting features in the use of class *B* insulation, especially for glass. (Class *B* insulation consists of inorganic material such as mica and asbestos in built-up form combined with binding substances.) Whether or not these synthetic materials have sufficiently longer life at high temperature to warrant new limits being set for them in the standards will be discussed, and it is hoped that new test procedures and other methods of evaluation of life-temperature characteristics will be suggested as a result.

A second technical session is proposed to cover motor-testing methods and is expected to include three papers. The first two papers would deal with methods of measuring temperatures on motors of various types, special attention being given to totally enclosed and other protected types of motors which so rapidly are growing in importance. The third paper would present a new method of measuring stray-load losses of polyphase induction motors that permits of greater convenience and accuracy than present common methods. If this new test method proves acceptable, it is expected to be included in the next revision of the AIEE test code. Following discussions of these papers, this session also would be resolved into an informal conference, at which the subject of the third session will be introduced by informal speakers.

It is proposed that the third and final session of the symposium deal with principles of rating of apparatus, and include five papers. The first of these would give a broad review of the factors to be considered in establishing rating limits of apparatus, including the history of previous work in this field. The second would deal with the principles of rating of general-purpose motors, and propose a modified temperature-breakdown torque system of rating intermediate between the present temperature system of transformer rating and the stalling torque system generally employed for mechanical apparatus. A third paper would deal with the rating and application of motors specifically for refrigeration and air-conditioning purposes. Another paper is proposed to deal with the rating of motors used on short-time duty cycles, including frequent starting or reversing. The final paper would deal with the effects of temperature on the mechanical performance of rotating machinery, showing some of the limitations due to bearing performance, expansion and contraction of insulation, and other factors that must be overcome before much higher temperatures can be employed economically in general industrial service.

Further details pertaining to the program of this symposium will be announced later.

Winter-Convention Committee

The personnel of the 1939 winter-convention committee is as follows: T. F. Barton, *chairman;* G. E. Dean, E. E. Dorting, F. M. Farmer, L. C. Miller, H. S. Osborne, J. H. Pilkington, A. L. Powell, C. S. Purnell, George Sutherland, and W. W. Truran.

Medals Awarded by AWS. The Samuel Wylie Miller Award and the J. F. Lincoln Award of the American Welding Society were presented at the opening session of the 1938 annual meeting of the society, October 17. The Miller medal was presented to J. W. Meadowcroft, of the Edward G. Budd Manufacturing Company, Philadelphia, Pa. The Lincoln Award was made in duplicate to J. C. Hodge and C. R. Sadler, of The Babcock and Wilcox Company, New York, N. Y., for a joint paper entitled "Weldability and Properties of Materials for Casing Strings."

Portions of downtown Brooklyn and New York showing the Hudson Avenue (Brooklyn) generating station of the Consolidated Edison System, the Manhattan and Brooklyn Bridges, and the downtown New York skyline in the background

AIEE Board of Directors Meets at Institute Headquarters

THE regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on October 25, 1938.

There were present: *President*—John C. Parker, New York, N. Y. *Vice-Presidents*—F. C. Bolton, College Station, Tex.; Chester L. Dawes, Cambridge, Mass.; F. M. Farmer, New York, N. Y.; A. H. Lovell, Ann Arbor, Mich.; I. Melville Stein, Philadelphia, Pa.; Edwin D. Wood, Louisville, Ky. *Directors*—C. R. Beardsley, C. R. Jones, H. S. Osborne, New York, N. Y.; F. Ellis Johnson, Madison, Wis.; W. B. Kouwenhoven, Baltimore, Md.; L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; C. A. Powel, East Pittsburgh, Pa. *National Secretary*—H. H. Henline, New York, N. Y.

Regrets were presented from Past President A. M. MacCutcheon and National Treasurer W. I. Slichter, both out of the United States.

Minutes of the board of directors meeting held on August 2, 1938, were approved.

Executive committee action, as of September 21, 1938, on applications was reported and confirmed, as follows: 2 applicants transferred and 1 elected to the grade of Fellow; 20 applicants transferred and 5 elected to the grade of Member; 31 applicants elected to the grade of Associate; 11 Students enrolled.

Reports were presented and approved of meetings of the board of examiners held on September 15 and October 20, 1938; and, upon the recommendation of that board, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 8 applicants were elected to the grade of Member; 31 applicants were elected to the grade of Associate; 601 Students were enrolled.

Monthly disbursements were reported by the finance committee, and approved, as follows: August, $17,951.13; September, $16,698.46; October, $25,109.51.

A budget for the appropriation year beginning October 1, 1938, submitted by the finance committee, was adopted. (Information concerning the budget appears elsewhere in this issue.)

Dates for previously authorized District meetings, selected by the District officers concerned, were approved as follows: April 17–19, 1939, for South West District meeting, Houston, Tex.; May 3–5, 1939, for North Eastern District meeting, Springfield, Mass.; September 27–29, 1939, for Great Lakes District meeting, Minneapolis, Minn.

Consideration was given to the paragraph prescribing an interval of at least six weeks between any two meetings, contained in the statement of policy to be followed in arranging schedules of Institute meetings, which was adopted by the board of directors in April 1928. Upon the recommendation of the committee on planning and co-ordination, in view of the shorter time now required for the preparation of papers for meetings, this paragraph was changed to read as follows:

The dates should be so arranged that there will be a suitable interval between the two meetings nearest to each other—preferably not less than three weeks.

To conform with the board's action, in August, merging three technical committees into one, Section 65 of the By-laws was amended by the deletion of the names of the committees on applications to iron and steel production, applications to mining work, and general power applications, and the addition of the name of the new committee on industrial power applications.

The board approved the following statement of scope of the committee on industrial power applications, upon the recommendation of the technical program committee:

Treatment of all matters in which the dominant factors are the applications of electric power to industries (exclusive of applications within the central station industry, power generation, transportation, marine work, electric welding, electrochemistry and electrometallurgy, and illumination, which are functions of other designated technical committees). Such subjects as motor control—the combination of motor, control, and driven machine into a functioning unit, all applications to iron and steel production (exclusive of electric furnaces) and to mining work, together with the requirements of specialized devices, materials, or constructions peculiar to such applications, are properly within the scope of this committee.

Approval was given to a recommendation of the technical program committee that Section 93 of the By-Laws be amended, to reduce the present 90-day limit to one of 60 days, for the receipt of papers for presentation at a national meeting or convention of the Institute. It was understood that the proposed amendment will take the prescribed course for official adoption, and that in the meantime the technical program committee will proceed on the basis of the revised by-law.

Upon petition of the Muscle Shoals Section and the recommendation of the Sections and finance committees, and with the acquiescence of the Alabama Section, the board authorized the transfer of Marshall and Madison Counties, Alabama, from the territory of the Alabama Section to that of the Muscle Shoals Section.

Due to the transference of the engineering school of the University of North Carolina at Chapel Hill to the North Carolina State College at Raleigh the former University of North Carolina Branch of the Institute officially was declared terminated.

The following board members were elected to serve as members of the national nominating committee for the present year: C. R. Beardsley, F. M. Farmer, A. H. Lovell, C. A. Powel, R. W. Sorensen. A. M. MacCutcheon was designated an alternate, and the president was empowered to appoint any additional alternates that may be required.

The following representatives and alternate of the Institute on the American Engineering Council assembly were appointed for the year beginning January 1, 1939:

C. O. Bickelhaupt, *chairman*, AIEE delegation
W. H. Harrison
C. R. Jones
C. R. Stephens
H. H. Henline, *alternate*

(The fifth representative, President Parker, is serving for the administrative year of the Institute, August 1, 1938, to August 1, 1939)

R. E. Hellmund was appointed an Institute representative on the standards council of the American Standards Association for the three-year term beginning January 1, 1939, to succeed A. M. MacCutcheon, whose term will expire December 31, 1938. H. H. Henline, H. S. Osborne, and E. B. Paxton were appointed alternates on this body for the year 1939.

Consideration was given to an invitation to appoint an Honorary Member of the Institute, if feasible, as a member of the board of award of the Marston gold medal, established by Iowa State College, through the generosity of Anson Marston, a former professor of civil engineering and dean of engineering of the college—the board of award to consist of nine members, four alumni, one honorary member, each, of the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Chemical Engineers and AIEE, and the dean of engineering who will serve as ex-officio chairman of the board; the first appointee of the Institute to serve for two years and subsequent appointees for four years. The board of directors appointed Past President and Honorary Member Bion J. Arnold as such representative of the Institute, for the term of two years.

The board accepted an invitation of the American Society for Testing Materials for the Institute to join with others in the formation of an American co-ordinating committee on corrosion and to appoint one representative thereon. H. S. Phelps was appointed the Institute's representative.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

John Fritz Medal for 1939 Awarded to F. B. Jewett

The John Fritz Gold Medal for 1939 has been awarded to Doctor F. B. Jewett (A'03, F'12) for "vision and leadership in science, and for notable achievement in the furtherance of industrial research and development in communication." This medal, the

Future AIEE Meetings

Winter Convention
New York, N. Y., January 23–27, 1939

South West District Meeting
Houston, Texas, April 17–19, 1939

North Eastern District Meeting
Springfield, Mass., May 3–5, 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Great Lakes District Meeting
Minneapolis, Minn., September 27–29, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Summer-Convention Goers May See Exposition

MEMBERS and their families attending the AIEE summer convention in San Francisco, Calif., June 25–29, 1939, may see the results of the latest advancements in efficient and artistic treatment of interior and exterior areas, pools, and lagoons at the Golden Gate International Exposition which opens late in February 1939. Exposition engineers are already working nightly on the location and adjustment of the floodlight and other types of units to enhance the amazingly beautiful architectural features of the buildings and grounds. Over 12,000 kw in power will be required by the lighting alone.

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highest distinction bestowed jointly by the four national societies of civil, mining and metallurgical, mechanical, and electrical engineers of the United States for "notable scientific or industrial achievement," will be presented with suitable ceremonies at one of the sessions of the AIEE winter convention, to be held at New York January 23–27, 1939.

Doctor Jewett is vice-president of the American Telephone and Telegraph Company and president of Bell Telephone Laboratories, Inc., New York; he was president of the Institute 1922–23. A biographical sketch of Doctor Jewett may be found in the "Personals" section of this issue.

Award of the John Fritz Medal is made not oftener than once a year, and is without restriction on account of nationality or sex. It is a memorial to the late John Fritz, a leader in the American iron and steel industry, to whom the first medal was awarded in 1902. The present board of award is composed of 16 members, each participating society having 4 representatives. AIEE representatives (all past presidents) on the board making the present award were A. W. Berresford (A'94, F'14), J. B. Whitehead (A'00, F'12), A. M. MacCutcheon (A'12, F'26), and W. H. Harrison (A'20, F'31).

ASME Elects Officers. The American Society of Mechanical Engineers has announced the election of the following new officers for 1939: *president*, A. G. Christie, The Johns Hopkins University, Baltimore, Md.; *vice-presidents*, H. H. Snelling, Snelling and Hendricks, Washington, D. C.; W. L. Dudley, Western Blower Company, Seattle, Wash.; Alfred Iddles, Babcock and Wilcox, New York, N. Y.; and J. W. Parker, The Detroit Edison Company, Detroit, Mich. Those elected to managerships of the Society were Clarke Freeman, Manufacturers Mutual Fire Insurance Company, Providence, R. I.; W. H. Winterrowd, Franklin Railway Supply Company, Chicago, Ill.; and W. R. Woolrich, University of Texas, Austin. The new officers will assume their duties on December 9, 1938.

AIEE National and District Prizes for Papers

Provision in the Institute's 1938–39 budget has been made for cash awards to accompany the national and District prizes for initial and Branch papers to be awarded during the current year, as indicated below.

All technical papers presented before the Institute during the year are eligible under the AIEE paper prize regulations for competitive consideration for one or more of the established prizes, regardless of whether presented before a Branch meeting, a Section meeting, a District meeting, or a national convention, the several classes providing for equitable competition. With the exception of the prizes for Branch papers, both District and national prizes are awarded each spring for papers presented during the preceding calendar year. For Branch papers, both national and District prizes are awarded on the basis of the academic year, July 1 to June 30, inclusive. Suitable certificates accompany all awards.

National prizes that may be awarded annually, and those to be accompanied by cash awards during the current year, are as follows:

1. Best paper prizes:
   Engineering practice
   Theory and research
   Public relations and education
2. Prize for initial paper ($100)
3. Prize for Branch paper ($100)

District prizes that may be awarded annually, together with the cash awards provided for the current year, are:

1. Prize for best paper
2. Prize for initial paper ($25)
3. Prize for Branch paper ($25)
4. Prize for graduate student paper

Although all papers presented are *eligible*, there is no provision for automatic consideration of papers, except that those approved by the technical program committee and presented at national conventions or District meetings will be considered by the national prize committee for the national "best paper" and the "initial paper" prizes without being offered formally for competition. All other papers for which prize consideration is desired must be *submitted* specifically for that purpose, through the District secretary for District prizes, or through the national secretary's office for the national prizes.

Deadline Dates

Papers to be considered for 1938 national prizes must be submitted not later than February 15, 1939. Papers to be considered for the District "best" and "initial" paper prizes must be submitted on or before February 15, 1939; for the District, Branch, and graduate student paper prizes, before July 15, 1939 (for papers presented during the academic year ending June 30, 1939). Those wishing further information may obtain a booklet entitled "National and District Prizes" by writing to AIEE Headquarters, 33 West 39th Street, New York, N. Y.

Coaxial-Cable System Changed. Tests, adjustments, and modifications of the two-megacycle coaxial-cable system between New York, N. Y., and Princeton, N. J., have been made by Bell Telephone Laboratories during the last few months. Equalizers and power-separation filters in all repeaters were modified to obtain improved characteristics, and methods of obtaining greater precision of equalization and regulation are being studied. Satisfactory test conversations were held over a circuit 2,100 miles long, which was built by looping conductors back and forth through the coaxial system a total of 20 times. This circuit consisted of four voice-frequency links in tandem. Using channels located in different parts of the frequency band between 100 and 1,900 kilocycles, the conversation passed through 64 steps of modulation in each direction and through each amplifier 20 times, giving the equivalent of 420 amplifiers in each direction.

The Institute Budget for the Year 1938-39

THE continuance of all Institute activities considered to be of the greatest benefit to the membership, and in some instances an enlargement of the present program, are provided for in the 1938–39 budget adopted by the board of directors at its meeting held on October 25, 1938.

Upon the recommendation of the finance committee that a balanced budget be adopted, and with the knowledge that the total of the required appropriations for Institute activities slightly exceeded the total revenue anticipated for the corresponding period, the board voted to make available $11,000 of the surplus of approximately $12,300 from the operations of the preceding appropriation year. This action was taken with the realization that certain expenditures provided for last year, amounting to about $5,000, have been deferred until the present year, and that the unusually large item for traveling expenses due to holding the 1939 summer convention in San Francisco did not represent a continuing expense. It was felt that a curtailment of any service to the membership this year to offset this temporary unbalance of the budget would not be justified.

Other important activities, such as Institute publications, National and District meetings, and Sections and Branches, have been appropriated for to a greater extent than reflected by the expenditures of the past year, as indicated in the accompanying budget tabulation.

Any presentation of the Institute budget, however brief, would not be complete without mention of the vital necessity for prompt and full realization of the expected revenue from membership dues, from which source is received more than two-thirds of the total income of the Institute.

Institute Income and Expenses for Year Ending September 30, 1938, and Budget for Year Ending September 30, 1939

	Actual Income and Expenses, Year Ending 9-30-38	Budget for Year Ending 9-30-39
Income		
Dues	$193,179.99	$199,000.00
Students' fees	11,922.00	11,500.00
Entrance fees	6,735.75	6,000.00
Transfer fees	1,045.00	1,000.00
Advertising	29,917.78	30,000.00
ELEC. ENGG.—nonmem. subscriptions	15,021.52	15,000.00
TRANS. subscriptions	6,224.66	6,500.00
Miscellaneous sales	10,406.61	9,000.00
Badge sales	1,821.90	1,800.00
Interest on securities	9,823.38	8,200.00
		288,000.00
Transferred from last year's surplus		11,000.00
Total	$286,098.59	$299,000.00
Expenses		
Publications:		
Text matter (ELEC. ENGG. & TRANS.)	†$70,259.87	*$72,900.00
Preprints	5,829.43	8,600.00
Advertising section	15,574.60	15,600.00
Year Book	6,482.32	6,500.00
Miscellaneous expense	1,515.80	2,000.00
Institute meetings	13,766.39	14,000.00
Institute Sections:		
Appropriations	23,174.94	24,300.00
Other expenses	5,645.72	5,800.00
Institute Branches:		
Meetings expenses	955.85	1,000.00
Other expenses	2,089.81	2,400.00
Committees:		
Edison Medal	349.96	200.00
Finance	1,600.00	1,600.00
Headquarters	90.10	250.00
Membership	7,949.53	8,350.00
Model registration law	9.48	600.00
Standards	5,830.98	7,500.00
Technical	158.52	250.00
Traveling Expenses:		
Geo. Dist. exec. committees	1,954.40	2,500.00
Section delegates to summer conv.	4,322.96	11,300.00
Counselor delegates to summer conv.	837.76	1,500.00
Dist. secys. to summer conv.	651.16	1,250.00
District Student conferences	6,430.37	6,500.00
President's appropriation	106.25	1,500.00
Vice-presidents	255.84	500.00
Board of directors	4,089.03	8,300.00
National nominating committee	1,062.55	1,050.00
AIEE representatives	10.05	100.00
Administration:		
Headquarters' salaries	34,395.22	35,000.00
Postage	4,076.52	3,800.00
Stationery & printing	3,945.74	3,800.00
Office equipment	441.13	200.00
Trav. expense, insurance, misc. supplies & services	2,795.56	3,200.00
Paper prizes	356.50	400.00
Joint activities:		
American Engineering Council	12,000.00	6,000.00
American Standards Assn.	1,500.00	1,500.00
Engrs. Council Prof. Dev.	850.00	850.00
Engg. Foundation research proj.:		
Impregnated paper insulation		250.00
Welding		250.00
Engg. Soc. Employment Service	1,162.56	1,763.00
Engg. Soc. Library	9,689.28	9,700.00
John Fritz Medal	50.00	260.00
United Engg. Trustees building assessment	11,005.44	11,000.00
U.S. Natl. Com. I.C.I.	300.00	300.00
Miscellaneous printing, etc.		4,100.00
Authors' reprints	1,798.71	
Reprints of standards	1,173.83	
Lightning Reference Book	385.34	
Miscellaneous	409.63	
Other expenses		
Membership badges	2,090.81	1,750.00
Text paper & env. in storage	2,397.04	
Retirement salary	1,125.00	
Miscellaneous	825.35	310.00
Total	$273,777.33	$290,783.00

* Actual budget of $75,200.00 reduced by text paper inventory of $2,300.00
† Actual expense $71,318.48, including paper costs paid for previously.

Radio City Music Hall in New York City has been an attraction to those attending AIEE winter conventions ever since it was completed. This view shows the staircase in the grand foyer, with mirrors three stories high, and Ezra Winter's mural "The Fountain of Youth." Each of the two chandeliers is 29 feet long and weighs approximately two tons

District 7 Award for Branch Paper

Prize for Branch paper in the AIEE South West District has been awarded to Harry N. Stafford, Enrolled Student of Eastland, Tex., for his paper "The Effect of Current-Wave Distortion on Energy Measurement," presented at a student convention at the University of Kansas, Manhattan, April 15, 1938. The award was made in accordance with the prize rules as given in the April 1937 issue of ELECTRICAL ENGINEERING, page 492.

NRC Insulation Conference Held at Pittsburgh

Bringing together dielectric experts from educational institutions, research laboratories, electrical manufacturers, and equipment users, the conference on electrical insulation of the National Research Council division of engineering and industrial research held its eleventh annual meeting November 3–4, at Pittsburgh, Pa. Official registration totalled 111. Some 20 papers on a wide variety of dielectric subjects were presented during the three technical sessions. Brief digests of these papers are scheduled for inclusion in a future issue.

Following the preliminaries at the opening session, J. B. Whitehead (A'00, F'12) chairman of the conference since its organization, presented his annual report, in which he reviewed the work of the conference during the past year. He also outlined the activi-

ties of the various committees during the year, as follows:

Committee on Physics. The committee on physics held a successful meeting in Washington, D. C., during the spring meeting of the American Physical Society. A feature of this meeting was the participation of the subcommittee on electrical measurements of glass of committee *D*-9 of the American Society for Testing Materials. A series of reports was presented on a program of comparative measurements of glass in the high-frequency range. Other members presented brief informal reports on outstanding work in the general field of dielectrics. The technical meeting was held following a dinner tendered the Committee and its guests by Chairman Wheeler P. Davey.

Committee on Chemistry. The outstanding activity of this committee was the arrangement and conducting of a symposium on electrical insulating materials under joint auspices with the industrial and engineering division of the American Chemical Society, September 8, during the fall meeting of the Society in Milwaukee, Wis. (A report of this meeting was published in the October issue of ELECTRICAL ENGINEERING, pages 426–7; an address by F. M. Clark (A'24) "A Chemical Approach to the Problem of High Voltage Dielectrics" which was presented at a dinner session of that meeting, may be found elsewhere in this issue.) Chairman F. L. Miller of the committee has other plans for further extending its usefulness.

Committee on Monographs. This committee has been very active in forwarding the production of a voluminous work on "The Electrochemistry of Dielectrics," by Glockler and Lind, originally planned as a monograph for the series published under the auspices of the conference. This work assumed such large proportions as to indicate the advisability of independent publication. Other monographs in view are "The Mapping of Electric Fields," by Ernst Weber (A'31, F'34), and "Solid Dielectrics" by S. O. Morgan and associates.

In accordance with his usual custom, Chairman Whitehead also included in his report a brief review of important contributions made during the past year to experimental research in the field of dielectrics and insulation; full text of that portion of his report is scheduled for publication in an early issue of ELECTRICAL ENGINEERING.

In addition to the technical sessions, the meeting included also the annual dinner followed by an evening session during which an address "A Simple Derivation of the Maxwell-Boltzmann Law" was delivered by Doctor E. U. Condon of the Westinghouse research laboratories. The meeting schedule included also inspection trips to nearby points of interest. The 1939 meeting of the conference will be held at Harvard University, Cambridge, Mass., the date to be selected later.

Additional Curricula Accredited at Sixth Annual Meeting of ECPD

MARKING the culmination of five years of existence, the Engineers' Council for Professional Development held its sixth annual meeting in New York, N. Y., October 21–22, 1938. Included in the program were the election of officers and appointment of committees, presentation of annual reports by the chairman and committees, and a dinner meeting at which informal talks were given by ECPD officers and others.

A joint organization, ECPD is composed of representatives of the sponsoring societies, of which the AIEE is one; the others are the national societies of civil, mechanical, mining and metallurgical, and chemical engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners. Its purpose is to enhance the professional status of the engineer. Its initial project has been the development of the young engineer, and this has been carried on through the efforts of four committees dealing with four stages in the evolution of the young engineer: student selection and guidance; engineering schools, professional training, and professional recognition.

A CONTINUING, PERMANENT AGENCY

In his annual report, Chairman C. F. Scott (A'92, F'25, HM'29) emphasized the idea of ECPD as a continuing, permanent agency. "In the first five years," he said, "we have been pioneering . . . in objectives, in co-operation, in scope, in method, and in results. Engineering groups have concerned themselves primarily with technological progress; through ECPD they now stress development of the individual engineer. . . . ECPD is . . . both exploratory and promotional. It proposes measures and, on approval, administers them primarily 'through the co-operative support' of the constituent organizations."

Speaking of the accomplishments of ECPD committees, Chairman Scott said: "Accrediting in engineering schools is acclaimed as the great achievement of ECPD." He characterized as a major problem the qualification of advisors, particularly high school staffs and local engineers, in the selection of the best qualified students for engineering courses. In answer to the question "After graduation—what?" Chairman Scott called attention to the great opportunity of the engineering societies to serve the profession by assisting the young engineer to continue his professional training after graduation looking toward the goal of "professional recognition."

"All this pioneering," Chairman Scott continued "proves that our projects are valuable, and continuing, and enlarging. In accrediting, our printed lists are not the end of the road, but the first milestone on a new highway. In a changing world, engineering must change, and our projects open a vision showing ways in which engineering can be made continuously better. If progressive engineering is basic to progressive civilization, our projects merit our full support through adequate organization and ample funds."

MAJOR COMMITTEES REPORT

Most significant of the reports presented and acted upon at this meeting was that of the committee on engineering schools. In approving the report of this committee, which was presented by its chairman, Karl T. Compton (F'31), ECPD expanded its list of accredited engineering curricula to include a total of 472 courses in 112 educational institutions throughout the country. The complete list, together with an outline of the basis of accrediting, is given in the excerpts from the report of this committee appearing elsewhere in this issue.

After outlining the direction of effort of the committee on selection and guidance of engineering students, R. L. Sackett, chairman, briefly described the various ways in which the guidance problem is being attacked. He also reported on the extent of distribution of the booklet "Engineering: A Career—A Culture," reporting that about 18,000 copies had been sold since October 1937. Since only 25,000 copies remain in stock, he recommended that provision be made for early editorial review, publication, and more aggressive distribution of a revised and enlarged edition of this booklet. Chairman Sackett's report aroused considerable discussion, at the conclusion of which it was voted that an amount not to exceed $200 be allowed the committee for preparation of a manuscript for a revised booklet, to be submitted to ECPD for approval.

Following a restatement of the objective of the committee on professional training and a review of its past accomplishments, Chairman O. W. Eshbach of this committee presented a summary of committee activities during the year 1937–38. He reported that of the 2,000 copies of the pamphlet "Suggestions to Juniors and General Reading List" all but about 100 copies had been distributed; of the 2,000 copies of "Selected Bibliography of Engineering Subjects," between 500 and 700 copies of each of the various sections remain in stock; and approximately 1,000 copies of the pamphlet "University Extension Facilities," of the 2,000 printed, are still on hand. To clarify future plans of the committee, Chairman Eshbach reviewed the essential elements of professional development or training and briefly discussed problems that might be considered as fruitful fields of study. "There is a need to know more about the desires of youth, the influences which bring them into professional association, and the deficiencies in opportunity for them," he

New-Member Activity

Thanks to you who have already helped your Section membership chairman; others please send those names of prospective members at an early date.

National Membership Committee

List of Undergraduate Curricula of Educational Institutions Accredited by ECPD

(As of October 22, 1938, and subject to continual revision)

University of Alabama: Aeronautical, civil, electrical, industrial, mechanical, mining

University of Arizona: Civil, electrical, mechanical, mining

University of Arkansas: Civil, electrical, mechanical

Armour Institute of Technology: Chemical, civil, electrical, mechanical

Brooklyn Polytechnic Institute (*a*): Chemical, civil, electrical, mechanical

Brown University: Civil, electrical, mechanical

Bucknell University: Civil, electrical

University of California: Civil, electrical, mechanical, metallurgical (metallurgy), mining, petroleum

California Institute of Technology: Aeronautical (5-year course), chemical (5-year course), civil, electrical, mechanical

Carnegie Institute of Technology: Chemical, civil (*a*), electrical (*a*), industrial (management) (*a*), mechanical (*a*), metallurgical (*a*)

Case School of Applied Science: Chemical, civil, electrical, mechanical, metallurgical

Catholic University of America: Aeronautical, architectural, civil, electrical, mechanical

University of Cincinnati: Aeronautical, chemical, civil, electrical, mechanical

The Citadel: Civil

Clarkson College of Technology: Chemical, civil, electrical, mechanical

Clemson Agricultural College: Civil, electrical, mechanical

College of the City of New York (*a*): Civil, electrical, mechanical

University of Colorado: Architectural, civil, electrical, mechanical

Colorado School of Mines: Geological, metallurgical, mining, petroleum

Colorado State College: Civil, electrical, mechanical

Columbia University (*b*): Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Cooper Union Institute of Technology (*c*): Civil, electrical, mechanical

Cornell University: Chemical, civil, electrical, industrial (administrative), mechanical

Dartmouth College: Civil

University of Delaware: Civil, electrical, mechanical

University of Detroit: Aeronautical, architectural, civil, electrical, mechanical

Drexel Institute: Chemical, civil, electrical, mechanical

Duke University: Civil, electrical, mechanical

University of Florida: Civil, electrical, industrial, mechanical

Georgia School of Technology: Aeronautical, chemical (excluding co-operative curriculum), civil, electrical, mechanical

Harvard University (*e*): Civil, communication, electrical, industrial (engineering and business administration), mechanical, metallurgical (physical metallurgy), sanitary

Howard University: Civil, electrical, mechanical

University of Idaho: Civil, electrical, mechanical, metallurgical (metallurgy), mining

University of Illinois: Architectural, ceramic (technical option), chemical, civil, electrical, general (*e*), mechanical, metallurgical, mining

Iowa State College: Agricultural (*f*), architectural, chemical, civil, electrical, general (*e*), mechanical

State University of Iowa: Chemical, civil, electrical, mechanical

Johns Hopkins University: Civil, electrical, mechanical

University of Kansas: Architectural, civil, electrical, mechanical, mining

Kansas State College: Agricultural (*f*), architectural, civil, electrical, mechanical

University of Kentucky: Civil, metallurgical, mining

Lafayette College: Civil, electrical, industrial (administrative), mechanical, metallurgical, mining

Lehigh University: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Louisiana State University: Civil, electrical, mechanical, petroleum

University of Louisville: Chemical, civil, electrical, mechanical

University of Maine: Civil, electrical, general (*e*), mechanical

Marquette University: Civil, electrical, mechanical

University of Maryland: Civil, electrical, mechanical

Massachusetts Institute of Technology: Aeronautical, building engineering and construction, chemical, civil, electrical, electrochemical, general (*e*), industrial (business and engineering administration), mechanical, metallurgical (metallurgy), mining naval architecture and marine engineering, public health, sanitary

University of Michigan: Aeronautical, chemical, civil, electrical, engineering mechanics, mechanical, metallurgical, naval architecture and marine engineering, transportation

Michigan College of Mining and Technology: Civil, electrical, mechanical, metallurgical, mining

Michigan State College: Civil, electrical, mechanical

University of Minnesota: Aeronautical, chemical, civil, electrical, mechanical, metallurgical, mining (excluding mining in geology option), petroleum

University of Missouri: Civil, electrical, mechanical

Missouri School of Mines and Metallurgy: Ceramic, civil, electrical, metallurgical, mining (mine) (excluding mining geology option)

Montana School of Mines: Geological, metallurgical, mining

Montana State College: Civil, electrical, mechanical

University of Nebraska: Agricultural (*f*), architectural, civil, electrical, mechanical

University of Nevada: Electrical, mechanical, mining

University of New Hampshire: Civil, electrical, mechanical

University of New Mexico: Civil, electrical, mechanical

New Mexico State College: Civil, electrical, mechanical

New York University: Aeronautical, chemical (*a*), civil (*a*), electrical (*a*), mechanical (*a*)

New York State College of Ceramics (at Alfred University): Ceramic

Newark College of Engineering: Civil, electrical, mechanical

North Carolina State College: Ceramic, civil, electrical, mechanical

University of North Dakota: Civil, electrical, mechanical, mining

Northwestern University: Civil, electrical, mechanical

Norwich University: Civil, electrical

Ohio State University: Ceramic, chemical, civil, electrical, industrial, mechanical, metallurgical, mining (mine)

University of Oklahoma: Architectural, civil, electrical, mechanical, petroleum (production option)

Oklahoma Agricultural and Mechanical College: Civil, electrical, industrial, mechanical

Oregon State College: Civil (excluding business option), electrical (excluding business option), mechanical (excluding business option)

University of Pennsylvania: Chemical, civil, electrical, mechanical

Pennsylvania State College: Architectural, ceramic (ceramics), chemical, civil, electrical, electrochemical, fuel technology, industrial, mechanical, metallurgical (metallurgy), mining, petroleum and natural gas, sanitary

University of Pittsburgh: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining, petroleum

Princeton University: Chemical, civil, electrical, mechanical

Purdue University: Chemical, civil, electrical, mechanical

Rensselaer Polytechnic Institute: Aeronautical, chemical, civil, electrical, industrial, mechanical, metallurgical

Rhode Island State College: Civil, electrical, mechanical

Rice Institute: Civil, electrical, mechanical

University of Rochester: Mechanical

Rose Polytechnic Institute: Civil, electrical, mechanical

Rutgers University: Civil, electrical, mechanical, sanitary

University of Santa Clara: Civil, electrical, mechanical

South Dakota State College: Civil electrical, mechanical

South Dakota State School of Mines: Civil, electrical, metallurgical, mining

University of Southern California: Petroleum

Stanford University: Civil, electrical, mechanical, metallurgical, mining, petroleum

Stevens Institute of Technology (*e*): General

Swarthmore College: Civil, electrical, mechanical

Syracuse University: Civil, electrical, industrial (administrative), mechanical

University of Tennessee: Civil, electrical, mechanical

University of Texas: Architectural, civil, electrical, mechanical, petroleum (petroleum production)

Agricultural and Mechanical College of Texas: Civil, electrical, mechanical, petroleum

Texas Technological College: Civil electrical, mechanical

Tufts College: Civil, electrical, mechanical

Tulane University of Louisiana: Civil, electrical, mechanical

Union College: Civil, electrical

University of Utah: Civil, electrical, mechanical, metallurgical, mining

Utah State Agricultural College: Civil

University of Vermont: Electrical

University of Virginia: Civil, electrical, mechanical

Virginia Military Institute: Civil, electrical

Virginia Polytechnic Institute: Ceramic, chemical, civil, electrical, industrial, mechanical

Washington University: Architectural civil, electrical, industrial (administrative), mechanical

University of Washington: Aeronautical, ceramic, chemical, civil, electrical, mechanical, metallurgical, mining

State College of Washington: Architectural, civil, electrical (basic and hydroelectric, options), mechanical (basic option), metallurgical, mining (excluding mine administration and petroleum engineering option)

Webb Institute of Naval Architecture: Naval architecture and marine engineering

West Virginia University: Civil, electrical, mechanical, mining

University of Wisconsin: Chemical, civil, electrical, mechanical, metallurgical, mining

Worcester Polytechnic Institute: Civil, electrical, mechanical

Yale University: Chemical, civil, electrical, mechanical, metallurgical (metallurgy)

(*a*). Accrediting applies to both the day and evening curricula.

(*b*). Accrediting applies to the 4-year and 5-year curricula leading to the bachelor of science degree.

(*c*). Accrediting applies to day curriculum only. Action on evening curriculum deferred pending granting of degrees.

(*d*). Accrediting applies only to curriculum as submitted to ECPD and upon completion of which a certificate is issued by Harvard University certifying that the student has pursued such a curriculum.

(*e*). The accrediting of a curriculum in general engineering implies satisfactory training in engineering sciences and in the basic subjects pertaining to several fields of engineering; it does not imply the accrediting, as separate curricula, of those component portions of the curriculum such as civil, mechanical, or electrical engineering that are usually offered as complete professional curricula leading to degrees in these particular fields.

(*f*). All accredited curricula in agricultural engineering have been provisionally accredited for a period of two years. The reason for this is twofold: First it appears to ECPD that the final year of the four-year program fails to build adequately upon the engineering basis laid in the first three years; secondly, it seems to ECPD that such curricula might better be given as options under one of the major engineering branches (i. e., civil, electrical, or mechanical engineering).

said. "At the same time, however, it is important to bring about unity in thinking on the part of those locally responsible for professional activities. Opinion should crystallize or grow out of experience with practical field situations. The committee, therefore, recommends that before it undertakes any further major activities a joint study be made, through the educational committees and Section chairmen of the several societies. This investigation should ascertain: (1) the nature of present activities, (2) the facilities available for them, (3) the manner in which they are sponsored and promoted, (4) the response to them. The report should attempt to crystallize opinion as to: (1) further policy (2) fields of activity of the several educational committees (3) means of co-ordination with local educational institutions and, if necessary, between societies (4) more effective ways of increasing membership." As future studies that might be undertaken if the required financial support could be obtained, Mr. Eshbach cited graduate study, opportunities for engineers, culture, co-operative education, and self-education.

A progress report of the committee on professional recognition was presented by J. W. Barker (M'26, F'30) member of this committee. He first reported what had been accomplished toward revision of the "Model Law for the Registration of Professional Engineers and Land Surveyors." He explained that the committee was concerned with uniformity in engineers registration laws, and not with the philosophy of registration. A voluminous collection of information concerning the methods of professional recognition used in other professions is being duplicated so that the committee can study it with a view toward later report and recommendation.

ECPD Officers Elected and Committees Appointed

As its chairman for the ensuing year, ECPD elected J. P. H. Perry, vice-president, Turner Construction Company, New York, N. Y. For vice-chairman, R. E. Doherty (A'16, M'27) president, Carnegie Institute of Technology, Pittsburgh, Pa., was named. S. L. Tyler, secretary, American Institute of Chemical Engineers, New York, N. Y., was elected secretary of ECPD; and C. E. Davies, secretary, The American Society of Mechanical Engineers, New York, N. Y., was re-elected assistant secretary. Chairmen of three committees were reappointed as follows: R. L. Sackett, student selection and guidance; Karl T. Compton (F'31) engineering schools; and O. W. Eshbach (A'17, F'37) professional training. C. F. Scott, retiring ECPD chairman, was appointed chairman of the committee on professional recognition.

Upon recommendation of the retiring executive committee, the following were reappointed to the executive committee for the ensuing year: C. F. Hirshfeld (A'05, F'36) representing The American Society of Mechanical Engineers [A. R. Stevenson, Jr. (A'20, F'37) alternate]; L. W. W. Morrow (A'13, F'25) representing the AIEE; H. C. Parmelee, representing the American Institute of Chemical Engineers; and D. B. Steinman, representing the National Council of State Boards of Engineering Examiners. Members newly elected to the executive committee were: E. R. Needles, representing the American Society of Civil Engineers; G. B. Waterhouse, representing the American Institute of Mining and Metallurgical Engineers; and R. E. Doherty (A'16, M'27) representing the Society for the Promotion of Engineering Education (Doctor Doherty was an alternate during 1937–38).

Appointments of the following representatives by the various societies for the three-year term 1938–41 were announced: ASCE, E. R. Needles (reappointment); AIME, G. B. Waterhouse (reappointment); ASME, H. T. Woolson; AIEE, J. F. Fairman (A'20, F'35); AIChE, W. N. Jones (reappointment); SPEE, C. C. Williams; and NCSBEE, N. W. Dougherty.

Report of ECPD Committee on Engineering Schools

In presenting the report of the ECPD committee on engineering schools, Chairman Karl T. Compton (F'31) restated the general objective of the committee and briefly reviewed the accomplishments of previous years. He said that at the end of 1937 (*EE Nov. '37, p. 1418*) 626 curricula at 129 institutions had been inspected, and final action taken on 617 curricula. Concerning activities during the current year, Chairman Compton said that "further material progress can be reported." He submitted recommendations on 62 additional curricula involving 6 institutions submitting curricula for the first time. Among those reinspected were 22 curricula previously accorded term accrediting, and 7 curricula initially not accredited. Including the additional curricula formally accredited by approval of this report, the current list includes 472 accredited undergraduate curricula at 112 institutions (see accompanying tabulation).

Basis for Accrediting Engineering Colleges

The following statement, proposed by the committee on engineering schools and approved by ECPD and by the constituent member organizations, embodies the principles in accordance with which accrediting is conducted.

I. Purpose of accrediting shall be to identify those institutions which offer professional curricula in engineering worthy of recognition as such.

II. Accrediting shall apply only to those curricula which lead to degrees.

III. Both undergraduate and graduate curricula shall be accredited. (Accrediting program at present embraces undergraduate curricula only.)

IV. Curricula in each institution shall be accredited individually. For this purpose, the ECPD will recognize the six major curricula: chemical, civil, electrical, mechanical, metallurgical, and mining engineering—represented in its own organization, and such other curricula as are warranted by the educational and industrial conditions pertaining to them.

V. Curricula shall be accredited on the basis of both qualitative and quantitative criteria.

VI. Qualitative criteria shall be evaluated through visits of inspection by a committee or committees of qualified individuals representing the ECPD.

VII. Quantitative criteria shall be evaluated through data secured from catalogs and other publications, and from questionnaires.

VIII. Qualitative criteria shall include the following:

1. Qualifications, experience, intellectual interests, attainments, and professional productivity of members of the faculty.
2. Standards and quality of instruction: (*a*) in the engineering departments; (*b*) in the scientific and other co-operating departments in which engineering students receive instruction.
3. Scholastic work of students.
4. Records of graduates both in graduate study and in practice.
5. Attitude and policy of administration toward its engineering division and toward teaching, research, and scholarly production.

IX. Quantitative criteria shall include the following:

1. Auspices, control, and organization of the institution and of the engineering division.
2. Curricula offered and degrees conferred.
3. Age of the institution and of the individual curricula.
4. Basis of and requirements for admission of students.
5. Number of students enrolled: (*a*) in the engineering college or division as a whole; (*b*) in the individual curricula.
6. Graduation requirements.
7. Teaching staff and teaching loads.
8. Physical facilities—the educational plant devoted to engineering education.
9. Finances: Investments, expenditures, sources of income.

Information supplied by means of the questionnaire, or otherwise, is for the confidential use of the ECPD and its agents and will not be disclosed without the specific written authorization of the institution concerned.

Commenting further on current progress, Chairman Compton said: "An important activity of the committee during the year has been the giving of advisory service to institutions which have had curricula not accredited, or at which curricula have been accredited for a limited term. In the case of seven curricula, the advisory service culminated in formal reconsideration. In other cases, although many suggested improvements have been made, the institutions are still unprepared to submit curricula for reinspection.

"During the year the committee has focused attention on plans for assuring the continuation of the accrediting program... Encouraging progress was made both in the direction of evolving a suitable plan for reinspection and review, and in the direction also of obtaining assurance of support from institutions."

Chairman Compton then outlined the extent of tasks remaining for the committee, and discussed some of the problems involved

in accrediting. Concerning the standards of accrediting, he said: "It has been noted that the committee has adhered rigidly to the policy that it should set no fixed standards for use as yardsticks in measuring the quality of engineering instruction. On the contrary, institutions and curricula are judged on broad, general grounds, rather than on details, and each institution is appraised in the light of local conditions. The committee strongly believes that there should be no rigid 'norm' for engineering education, and that institutions should be accorded wide latitude to decide for themselves upon educational policies.

"One principle is insisted upon, however, namely, that if any curriculum omits some portion of a subject in which engineers in that field are expected by the public to have competence, under such conditions the committee considers it a necessary safeguard to the public that the curriculum be not accredited.

"A direct source of gratification is the way in which institutions have been able to benefit from accrediting. Almost without exception the committees of inspection have been asked for suggestions and advice. A sincere effort has been made to meet these requests, and each committee of inspection conscientiously endeavors to notice ways along which efforts toward improvement might advantageously be directed. The appreciative comments and letters received, and the way in which suggestions have been acted upon speak for the success attained, in spite of some failures to do all that might have been done had time been adequate and human performance perfect. In addition, many institutions are using the list as a basis for admission to the engineering school of students transferring from other institutions.

"Another valuable feature of ECPD accrediting is the way in which it has eliminated multiplicity of accrediting in the field of engineering education. Several agencies not formally connected with ECPD have gratefully accepted the accredited list and during the past year notable success of the accrediting program was evidence in the unreserved endorsement of the list by the National Council of State Boards of Engineering Examiners. Thus one of the major objectives of the program has been met."

Chairman Compton concluded his report with an outline of major future activities for the committee and a summary of the committee's finances.

National Defense Power Committee Announces Standards for Turbine Generators

ACCORDING to an official release from the War Department, the National Defense Power Committee approved November 14 the report of its subcommittee on standardization establishing, for the first time in the history of the electrical industry, preferred standards for steam turbine-generators of 10,000 kilowatts rating and above with a view to expediting the production and reducing the costs of such equipment. The adoption of these standards is expected materially to accelerate the construction and erection of generating stations to provide additional supplies of electric energy. The committee is considering similar determinations for generators of smaller ratings.

Definite standards of pressure, temperature, voltage, power factor, and other technical features, are provided for nine sizes of condensing turbines, ranging from 10,000 to 100,000 kilowatts and for eight sizes of superposed turbines ranging from 10,000 to 60,000 kilowatts. In the past, turbines and generators of these large capacities have been chiefly "tailor-made jobs" built to order on special designs prepared by utility engineers. This has meant the expenditure of a large amount of time on engineering and design for each machine and in large part has prevented the adoption of quantity methods of production.

The subcommittee on standardization, of which Commissioner Basil Manly of the Federal Power Commission is chairman, while establishing these preferred standards, states that it "has been careful in its report to provide sufficient latitude for the modification of the standards to meet the special conditions arising in connection with the installation of new equipment in existing plants or where unusual physical conditions must be met. Provision also is made for the consideration of technical advances in the art. But in every case where deviation from the preferred standards is suggested, the burden of proof will be upon the utility or manufacturer proposing such deviation. The committee states that at all times it will welcome constructive suggestions from the industry.

These provisions are emphasized in the technical report prepared for the subcommittee by Dr. John C. Parker, president of the American Institute of Electrical Engineers and vice-president of the Consolidated Edison Company, representing the utilities;

Table I. Condensing Turbines

1	Rating (kw)	10,000	12,500	15,000	20,000	25,000	35,000	50,000	75,000	100,000
2	Revolutions per min.	3,600	3,600	3,600	3,600	3,600	3,600	3,600	1,800	1,800
3	Throttle pressure (pounds per sq in. gauge)	650	650	650	850	850	850 or 1,250	850 or 1,250	850 or 1,250	850 or 1,250
4	Throttle temp. (deg F)	825	825	825	900	900	900	900	900	900
5	Number of extraction openings	3	3	3	3	3	4	4	4	4
6	Temp. at extraction openings ± 10 deg F (at rated output)	170/225/290	170/225/290	170/225/290	170/225/290	170/225/290	170/225/290/350	170/225/290/350	170/225/290/350	170/225/290/350
7	Turbine capacity in % of kw rating	125	125	125	125	125	125	125	125	125
8	Power factor	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
9	Generator cooling	Air	Air	Air	Air	Air or hydrogen	Hydrogen	Hydrogen	Hydrogen	Hydrogen

General: All sizes—back pressure 1 inch or 1½ inch mercury absolute; short-circuit ratio 0.9; generator voltage 13,800*; excitation voltage 250.
* 11, 11.5, 12, 13.2, or 14.4 kv may be furnished if required to meet the needs of an existing system.

Table II. Superposed Turbines

10	Rating (kw)	10,000	12,500	15,000	20,000	25,000	35,000	50,000	60,000
11	Turbine capacity in % of kw rating	111	111	111	111	111	111	111	111
12	Power factor	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8 or 0.9
13	Generator cooling	Air	Air	Air	Air	Air or hydrogen	Hydrogen	Hydrogen	Hydrogen

General: All sizes—3,600 rpm; throttle pressure and temperature 1,250 pounds per square inch gauge, 925 degrees fahrenheit; back pressure 200–300 pounds per square inch gauge; short-circuit ratio 0.9; generator voltage 13,800*; excitation voltage 250.
* 11, 11.5, 12, 13.2, or 14.4 kv may be furnished if required to meet the needs of an existing system.

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 27–31, Richmond, Va.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 13–16, 1939, New York, N. Y.

American Physical Society. 224th meeting, December, Los Angeles, Calif.

40th annual meeting, December 27–29, Washington, D. C.

American Society of Civil Engineers. Annual meeting, January 18–20, New York, N. Y.

American Society of Heating and Ventilating Engineers. 1939 annual meeting, January 23–26, Pittsburgh, Pa.

American Society of Mechanical Engineers. Spring meeting, February 23–25, 1939, New Orleans, La.

Machine and tool progress exhibition, March 14–18, 1939, Detroit, Mich.

American Society of Testing Materials. Committee week, March 6–10, 1939, Columbus, Ohio

1939 annual meeting, June 26–30, Atlantic City, N. J.

National Electrical Manufacturers Association. Midwinter conference, February 5–11, 1939, New York, N. Y.

Society of Automotive Engineers. Annual meeting, January 9–13, 1939, Detroit, Mich.

interrelation with existing equipment clearly calls for special designs. Deviation from these proposed standards, if of decided advantage to the public, or if necessitated by physical conditions, or by the fundamental purpose of rapid creation of power facilities for national defense, will be deemed to be consistent with this program. In all such cases the burden of clear proof rests upon any one proposing such deviation.

"Illustrative of such cases in which deviation will be deemed to be in the spirit of this program—but not intended to be all inclusive—are the following:

(1) The temperature of condensing water supply may require turbines designed for operation with back-pressures higher than herein provided.

(2) The present availability in manufacturers' plants of turbine-generators well advanced in production points clearly to the completion and use of such equipment.

(3) Duplication of a turbine-generator, not currently discontinued by the manufacturer as an active design, may expedite manufacture and installation of power facilities.

(4) The manufacture and installation of turbine-generators adapted to meet essential requirements in existing stations may facilitate rapid creation of generating capacity.

"The preferred standards are intended to be progressive standards and, consistently with the fundamental purpose of expediting production and installation of power-generating equipment, are intended to permit technical and economic developments. To that end they should, at least annually, and as occasion seems clearly to warrant, be reviewed to determine whether advances in the art call for specific modification."

Those participating in the conferences which resulted in the recommendations of preferred standards were:

1. For the National Defense Power Committee—Assistant Secretary of War Louis Johnson; Federal Power Commissioner Basil Manly; Captain William R. Winslow; Mr. Thomas R. Tate; Lieutenant-Colonel L. E. Atkins and Mr. Carl H. Giroux, U. S. Army; Commander K. B. Bragg, U. S. Navy.

2. For the electrical equipment manufacturers: Allis-Chalmers Manufacturing Company—A. C. Flory, manager, steam turbine department; R. N. Landreth. General Electric Company—C. S. Coggeshall; A. F. E. Horn; A. R. Smith, manager, steam turbine department; A. O. White. Westinghouse Electric and Manufacturing Company—C. A. Bercaw; C. B. Campbell, manager, turbine department; G. H. Cox; Ralph Kelly; C. F. Lloyd; R. A. McCarty.

3. For the electric utilities: K. M. Irwin, vice-president in charge of engineering, Philadelphia Electric Company; H. B. Gear, vice-president, Commonwealth Edison Company of Chicago; Dr. John C. Parker, vice-president, Consolidated Edison Company of New York, Inc.

The accompanying tables show the preferred standards for steam turbine-generators adopted by the National Power Defense Committee's subcommittee on standardization.

C. S. Coggeshall, sales manager, turbine department of the General Electric Company, representing the electrical equipment manufacturers, and Thomas R. Tate, representing the National Defense Power Committee. This report states:

"Your subcommittee on standardization of turbine-generators has held two meetings, one on October 20, and another on November 3, at which representatives of the turbine generator manufacturers, utilities and the Government were present and co-operated wholeheartedly in discussing the adoption of preferred standards for steam turbine generators of 10,000 kilowatts rating and above. The subcommittee has unanimously agreed upon and recommends for adoption by industry and the manufacturers the standards set forth herein.

"The immediate objective of the establishment of preferred standards for turbine generators is the maximum speed of provision of power facilities to anticipate peacetime requirements and to facilitate wartime provision of power through elimination of any unnecessary special designs or sizes. It is expected, incidentally, that the cost of power plant installations will be reduced sufficiently to compensate for any added economy or other advantages that might result from more special designs.

"It is the belief of your subcommittee that the advantages of preferred standards as here recommended for turbine-generators will be reflected also in such associated equipment as boilers and appurtenances, steam piping, valves, and fittings.

"It is the intention that the preferred standards agreed upon by representatives of the Government, the manufacturers, and the utilities, will be followed in the building of all new generating stations and in all installations within existing stations unless

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., one of the joint agencies supported and participated in by the AIEE, was organized in 1904 as an instrumentality of the Founder Societies, the four national societies of civil, mining and metallurgical, mechanical, and electrical engineers. Its purpose is the managing of property and funds in which these societies have joint interests, and it is governed by trustees duly appointed by the societies as their representatives. It maintains two departments: (1) the Engineering Societies Library, and (2) The Engineering Foundation.

The corporation (UET, Inc.) manages the Engineering Societies Building and all trust funds placed in the hands of UET, Inc.

The Engineering Societies Library is a free public engineering library, which is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

The Engineering Foundation, founded by the late Ambrose Swasey in 1914, is entrusted with the expenditure of income from endowment and other funds. The ultimate objective of Foundation is stated to be: "for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind."

In the accompanying articles may be found announcements of the elections recently held by UET and The Engineering Foundation, and abstracts of the annual reports of these organizations and of the Engineering Societies Library.

Election of Officers of United Engineering Trustees, Inc.

Officers to serve the United Engineering Trustees, Inc., for the year 1938–39 were elected at the recent annual meeting of UET. D. Robert Yarnall, chief engineer of the Yarnall-Waring Company, Philadelphia, Pa., was re-elected president, and H. A. Lardner (A'94, F'13) and Albert Roberts were re-elected vice-presidents. Other officers re-elected were H. R. Woodrow (A'12, F'23) treasurer; J. P. H. Perry, assistant treasurer; and John H. R. Arms, secretary and general manager; the first five comprise the executive committee.

Members of the board of trustees of UET for the year 1938–39, including both new and hold-over members, are:

Terms expiring October 1939

J. P. Hogan	ASCE representative
Albert Roberts	AIME representative
D. Robert Yarnall	ASME representative
H. P. Charlesworth (M'22, F'28, past-president)	AIEE representative

Terms expiring October 1940

Otis E. Hovey	ASCE representative
W. D. B. Motter, Jr.	AIME representative
Kenneth H. Condit	ASME representative
H. R. Woodrow (A'12, F'23)	AIEE representative

Terms expiring October 1941

A. L. J. Queneau — AIME representative
F. M. Farmer (A'02, F'13, vice-president) — AIEE representative

Terms expiring October 1942

J. P. H. Perry — ASCE representative
Henry A. Lardner — ASME representative

Of these, J. P. H. Perry and Henry A. Lardner were reappointed; all others are held over. The following committees were reappointed:

Finance: Albert Roberts, chairman; J. P. Hogan, H. A. Lardner, H. R. Woodrow, D. Robert Yarnall, ex-officio.

Real Estate: J. P. H. Perry, chairman, A. L. J. Queneau, Kenneth H. Condit, H. P. Charlesworth, D. Robert Yarnall, ex-officio.

Engineering Foundation Elects Officers

At the recent annual meeting of The Engineering Foundation, F. M. Farmer (A'02, F'13, vice-president) was re-elected chairman for the year 1938–39, and George E. Beggs was elected vice-chairman. These two, together with A. L. J. Queneau, W. I. Slichter (A'00, F'12, national treasurer), and K. H. Condit, comprise the executive committee.

Other re-elections were O. E. Hovey, director, and John H. R. Arms, secretary.

These officers and the executive committee of The Engineering Foundation are elected by the Foundation board, from among its own members. The board is itself elected by the board of trustees of United Engineering Trustees, Inc. The complete membership of the Engineering Foundation board for the year 1938–39 is:

Name		Term Expires
Four Trustees of UET, Inc.		
A. L. J. Queneau	AIME	1941
K. H. Condit	ASME	1939
H. P. Charlesworth	AIEE	1939
O. E. Hovey	ASCE	1941
Eight Members Nominated by Founder Societies		
George D. Barron	AIME	1940
George E. Beggs	ASCE	1939
F. F. Colcord	AIME	1942
F. M. Farmer	AIEE	1939
W. H. Fulweiler	ASME	1940
E. M. T. Ryder	ASCE	1942
W. I. Slichter	AIEE	1940
Albert E. White	ASME	1939
Three Members-at-Large		
O. B. Buckley	AIEE	1942
John V. N. Dorr	AIME	1939
Edwards R. Fish	ASME	1939
Ex-officio, President UET, Inc.		
D. Robert Yarnall	ASME	

Members of the research procedure committee as appointed or reappointed are:

F. F. Colcord, chairman, representing The Engineering Foundation.

K. H. Condit, representing The Engineering Foundation.

L. W. Chubb (A'09, F'21, past director) director, research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., representing AIEE.

W. H. Fulweiler, Philadelphia, Pa., representing ASME.

Sam Tour, Lucius Pitkin, Inc., New York, N. Y., representing AIME.

H. E. Wessman, New York University, New York, N. Y., representing ASCE.

F. M. Farmer, ex-officio.

The personnel of other committees as appointed or reappointed at this meeting is as follows:

IRON ALLOYS

G. B. Waterhouse, *chairman*, professor of metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., representing AIME.

Lyman J. Briggs, director, National Bureau of Standards, represented by J. G. Thompson, chief of section on chemical metallurgy, National Bureau of Standards, Washington, D. C.

J. W. Finch, director, United States Bureau of Mines, represented by R. S. Dean, chief engineer, Metallurgical Division, Washington, D. C.

J. T. MacKenzie, metallurgist and chief chemist, American Cast Iron Pipe Company, Birmingham, Ala., representing American Foundrymen's Association.

John Johnston, director of research, United States Steel Corporation, Kearny, N. J., representing American Iron and Steel Institute.

Bradley Stoughton, dean of engineering, Lehigh University, Bethlehem, Pa., representing American Society for Metals.

Jerome Strauss, vice-president, Vanadium Corporation of America, Bridgeville, Pa., representing American Society for Testing Materials.

T. H. Wickenden, metallurgical engineer, International Nickel Company, New York, N. Y., representing The Society of Automotive Engineers.

Table I. Summary of Annual Report of Finance Committee of UET, Inc.

Operation of Building

Operating revenue		$ 163,020.71
Less operating expenditures		157,834.49
Gross operating credit		5,186.22
Transferred to general reserve fund		1,500.00
Operating gain 1937–38		3,686.22
Operating credit from previous years		9,496.92
		13,183.14
Less accounts written off		145.00
Net balance September 30, 1938		$ 13,038.14

Operation of Library

Maintenance revenue	$ 46,707.84	
Maintenance expenditures	47,214.28	
Debit balance for year 1938	506.44	
Credit balance for previous year	6,578.67	
Credit balance September 30, 1938		$ 6,072.23
Service Bureau revenue	8,340.00	
Service Bureau expenditures and adjustments	7,978.18	
Credit balance for year 1938	361.82	
Credit balance from previous year	5,861.74	
Credit balance September 30, 1938		6,223.59
Total net operating credit balance cumulated to September 30, 1938		$ 12,295.79

Funds and Property

* **Combined Fund: Summary of Investments, September 30, 1938**

	Legal	Nonlegal	Book Value	Market Value
Funds included:				
Engineering Foundation fund	$491,710.60	$283,224.88	$ 774,935.48	
Edward Dean Adams fund		90,872.61	90,872.61	
Library endowment fund	92,240.18	75,209.90	167,450.08	
Depreciation and renewal fund		384,055.44	384,055.44	
General reserve fund		10,189.62	10,189.62	
Total	$583,950.78	$843,552.45	$1,427,503.23	
Investments: Legal			$ 346,422.00	
Nonlegal			1,075,702.89	
Total investment, September 30, 1938			1,422,124.89	$1,214,482.08
Cash uninvested			5,378.34	
			$1,427,503.23	
Real estate, cost of—September 30, 1938			$1,993,793.92	
Operating cash			24,770.37	
Accounts receivable, gross			1,558.95	
The Engineering Foundation—unexpended income			29,873.42	
Alloys of iron research—unexpended income			5,594.75	
The Engineering Foundation custodian fund assets			3,051.23	
Welding research—unexpended income			1,215.32	
Henry R. Towne engineering fund			50,349.36	$ 27,700.16
Fifth Swasey gift			86,977.16	$ 86,436.69
Total			$3,624,687.71	

Moneys Held for Special Purposes

Endowment committee (Adams expense fund)	$ 702.57	

UET, Inc., Custodian of John Fritz Medal Fund

Securities held September 30, 1938	$ 3,500.00	$ 3,517.50
Cash on hand September 30, 1938	277.23	

* A group of funds managed as one for convenience and economy in investment transactions.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y., representing American Electrochemical Society.

Wilfred Sykes (A'09, F'14, past manager) assistant to the president, Inland Steel Company, Chicago, Ill.; member-at-large.

F. T. Sisco, *editor*.

WELDING RESEARCH

C. A. Adams (A'94, F'13, past-president) *chairman;* consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.

H. C. Boardman, research engineer, Chicago Bridge and Iron Company, Chicago, Ill.

Everett Chapman, president, Lukenweld, Inc., Coatesville, Pa.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.

J. J. Crowe, engineer-in-charge of apparatus, research, and development department of Air Reduction Company, Jersey City, N. J.

A. S. Douglass, construction engineer, Detroit Edison Company, Detroit, Mich.

C. L. Eksergian, chief engineer, Budd Wheel Company, Detroit, Mich.

A. J. Ely, mechanical engineer, Standard Oil Development Company, Elizabeth, N. J.

H. M. Hobart (A'94, F'12, past vice-president) consulting engineer, General Electric Company, Schenectady, N. Y.

D. S. Jacobus (A'03) advisory engineer, The Babcock and Wilcox Company, New York, N. Y.

G. F. Jenks, colonel, Ordnance Department, United States Army, Washington, D. C.

Jonathan Jones, chief engineer, fabricated steel construction, Bethlehem Steel Company, Bethlehem, Pa.

P. G. Lang, Jr., engineer of bridges, Baltimore and Ohio Railroad, Baltimore, Md.

F. T. Llewellyn, research engineer, United States Steel Corporation, New York, N. Y.

Aubrey Weymouth, vice-president and chief engineer, Post and McCord, Inc., New York, N. Y. (Alternate for Jonathan Jones.)

William Spraragen (A'17, M'26) *secretary*, technical secretary and editor, New York, N. Y.

Chairman Farmer was reappointed Foundation's representative on the executive board of National Research Council, and O. E. Hovey was appointed representative on the highway research board.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for the year ending September 30, 1938, has been submitted to the AIEE and other participating societies by D. Robert Yarnall, president. The report reveals continued financial stability as a whole, practically full occupancy of the Engineering Societies Building, gratifying use of meeting halls, and greater protection of the building. The physical condition of the building has been maintained and during the year extensive deferred mechanical maintenance has been met. The property remains on the tax-exempt rolls. Gratuitous use of meeting rooms has been granted to federal, state, and municipal organizations for military and WPA projects, and in co-operation with WPA and the board of education of the City of New York, to adult education classes in mathematics, languages, and other popular subjects.

During the year, Ambrose Swasey's fifth gift was written onto the books at $86,977.16, bringing his gifts to a total book value of $818,632.91. The depreciation and renewal fund was brought to a total of $384,055.44 against a 32-year-old building carried at $1,453,793.92. The capital investment in the property has been increased $6,000 by the addition of library shelving for use of Engineering Societies Library, paid by assessment against the Founder Societies. This addition is expected to provide storage for library acquisitions for the coming five years. A summary of the report of the UET finance committee is given in table I.

Annual Report Issued by Engineering Societies Library

The annual report of the Engineering Societies Library, containing information on the use of the library, its finances, and acquisitions, for the year ending September 30, 1938, has been submitted to the AIEE and other participating societies by Harrison W. Craver, director.

The number of readers was 31,376, an increase of 4,626 over 1936–37. In addition the library aided 10,574 other persons in various ways: 121 by lending 141 books; 78 by making searches and copies; 113 by making translations; 2,590 by making 20,869 photoprints; 2,974 by letter; and 4,698 by telephone. By these various ways, the library was used by 41,950 persons, 4,973 more than in the previous year. Requests for assistance have covered a wide variety of subjects and have come from every part of the earth.

On October 1, 1937 the library contained 141,292 volumes, 7,330 maps, and 4,362 manuscript bibliographies. Additions during the year were 3,091 volumes, 118 maps, and 29 bibliographies. One hundred twenty-one volumes and 40 maps were withdrawn, making the stock at end of the year 144,262 volumes, 7,408 maps, and 4,391 manuscript bibliographies. In addition, 3,248 pamphlets were added to volumes already counted. The lending collection contained 703 volumes and the number of duplicates is approximately 12,000 volumes.

In addition to cataloging current accessions as received, work has been carried on throughout the year in recataloging the pamphlets in the Wheeler collection, to conform with the system now in use. With the exception of a collection of Russian pamphlets and one of trade catalogs, and a few recent gifts, all material is cataloged and available for use.

Through the continuation of a gift of W. S. Barstow (A'94, F'12), work has continued during the year on repairing and rebinding valuable old books.

The periodical index now contains over 225,000 references to important engineering articles, classified by the universal decimal system, of which 21,000 were added during the current year.

During the year 4,146 volumes, 9,748 pamphlets, 118 maps, and 29 bibliographies were acquired by purchase or gift, a total of 14,041 items. Of these 3,091 volumes, 3,248 pamphlets, 118 maps, and 29 bibliographies were added to the permanent collection, a total of 6,486 additions. Thirty-five other volumes were placed in the loan collection. The remaining items of possible usefulness were added to the duplicate collection, to be sold or exchanged as opportunity occurs; the residue was discarded as waste paper. Sales of duplicates amounted to $407.47.

The number of periodicals received currently was 1,369. Six hundred twenty-nine volumes, worth approximately $2,200 were received for review.

The gifts numbered 12,242 items. Among the donors were the American Institute of Chemical Engineers, Professor George E. Case, the Bridgeport Public Library, the *Engineering News-Record*, E. R. Fish, Miss B. Haupt, Mrs. William B. Jackson, M. Kammerhoff, the New York Bar Association, George A. Orrok, Port of New York Authority, Shepherd F. Smith, and Arthur F. Tuttle.

At the request of the officers of the Engineering Institute of Canada, arrangements were made to supply the *Engineering Journal*, the organ of the Institute, with notices of new books.

Physical improvements of considerable magnitude have been made. A special appropriation by the Founder Societies made possible the erection of additional shelving, which has relieved overcrowding.

The budget for general operations was $48,100. Of this $35,959.70 was appropriated by the Founder Societies as follows:

American Society of Civil Engineers	$9,631.40
American Institute of Mining and Metallurgical Engineers	7,520.90
American Society of Mechanical Engineers	9,118.10
American Institute of Electrical Engineers	9,689.30

Expenditures from this budget amounted to $47,214.28 of which $9,534.18 was spent for books and other equipment of permanent value. The service bureau received $8,340.00 and spent $7,942.04.

Annual Report Issued by Engineering Foundation

The annual report of The Engineering Foundation for the year ending September 30, 1938, has been submitted to the AIEE and other participating societies by F. M. Farmer (A'02, F'13, vice-president) chairman of the Foundation board, who was assisted by Otis E. Hovey, director.

A summary of the capital fund of The Engineering Foundation and a condensed financial statement follow:

Capital Funds

Endowment, total book value on September 30, 1938	$871,000.00
E. H. McHenry bequest in hands of executors until decease of two life beneficiaries, appraised at probate of will in 1931, approximately	$400,000.00
Fifth Swasey gift	$ 86,977.16

The capital funds are held and administered by United Engineering Trustees, Inc. The net income from endowment was $42,516.69 for the fiscal year ended September 30, 1938. The Foundation board has discretion in use of income. For many of the enterprises which the Foundation has aided, large contributions of money, services, and materials have been obtained from others.

Expendable Resources—Summary

Balance on October 1, 1937		$ 24,555.11
Receipts		
Income from endowment	$42,516.69	
Income from minor items	1,362.27	43,878.96
Total resources		$ 68,434.07

Disbursements—Summary

Research projects	$30,161.38	
Promotion of research and administrative expenses	8,399.27	
Total for furtherance and support of research		38,560.65
Balance on October 1, 1938		$ 29,873.42

Money "contributions" from organizations and individuals, for specific activities, passed through the Foundation's accounts from its organization to September 30, 1938, totaled $316,703.81.

During the report year, in order to carry out the purposes of the Foundation, a total of 72 projects dealing with engineering and technical research, and the broader non-technical matters of concern to the engineering profession had been or were being assisted by money grants. Work on 20 active projects, in 2 of which the AIEE is interested directly, has progressed during the year. In order to establish personal contacts and closer co-operation with those in charge of technical researches which are being supported or assisted by grants from the Foundation, the director has visited during the year most of the institutions and laboratories at which these researches are being conducted. A summary of activities follows:

Soil Mechanics and Foundations Division (ASCE). The following studies are included:

Earths, Dams, and Embankments ($500). Five subcommittees have been assigned to specific phases of the problem. The principal activity has been collecting data and ideas on the methods used for determining settlement in earth fills during and after construction, and for determining internal pressures in earth fills.

Sampling and Testing ($2,500). The work of the committee mainly has been studies for better methods of obtaining undisturbed samples and of the causes and effects of distortion and swelling of such samples. The work is being done with the co-operation of several laboratories, and interested companies.

Seepage and Erosion ($750). The project consisting of model investigations of seepage phenomena in earth dams has been continued at the University of Minnesota. A report is expected within the next few months.

Foundations ($1,500). Investigations have continued of structures in Europe. Data have been collected on settlements of structures in Egypt and papers on this and data on lateral earth and concrete pressures are to be presented.

Special Committee on Hydraulic Research (ASCE). The following studies are included:

Conversion of Kinetic to Potential Energy in Expanding Conduits ($300). The tests of a transparent conical expansion 7½ inches long connecting transparent pipes 3 inches and 5 inches in diameter, have been completed, and the tests of sudden expansion are nearly finished. A mass of photographic and statistical data has been collected and is being analyzed, and a report is expected during the coming year.

Traveling Waves on Steep Slopes ($300). The work has been on a study of traveling waves and bores in a channel of trapezoidal cross section 92 feet long, with slopes from zero to about eight degrees.

Phenomena of Intersecting Streams ($300). The work on open channel intersections has been suspended for the present and attention is being directed to intersections of closed conduits. It was found that better results could be obtained by this procedure.

Curves in Open Channels ($300). Data have been taken on velocity measurements at various sections of the bend of a rectangular section 18 inches wide and of varying depth up to 10 inches. These data have been plotted into curves showing the condition of flow. A mathematical analysis of stream lines, angular velocity, and acceleration has been made in accordance with the laws of hydrodynamics.

Sedimentation at the Confluence of Rivers ($300). A new apparatus has been built at the St. Anthony Falls Hydraulic Laboratory designed to overcome some of the short-comings of the original experimental setup.

Alloys of Iron (AIME, $5,000). During the year the manuscript for "The Alloys of Iron and Nickel, Volume I" was completed. The first draft of "The Alloys of Iron and Chromium, Volume II" was finished and prepared for review by the co-operating experts. Work has been continued in assembling the data for "The Alloys of Iron and Nickel, Volume II—Engineering Steels," "The Alloys of Iron and Manganese," and "The Alloys of Iron and Vanadium."

Barodynamic Researches (AIME, $2,500). Work on this project has been continued. The following investigations were made:

1. The effect of immediate roof thickness in longwall mining.
2. The effect of artificial support in longwall support.
3. Stress distribution in mine pillars by photoelastic means.
4. Stress distribution in mine bottoms and roofs by photoelastic means.
5. Time effects in the behavior of rock structures stressed beyond the elastic limits.

Several articles have been published and others are to follow.

Critical Pressure Steam Boilers (ASME, $1,000). The 1937–38 research program has included viscosity of steam and oxidation of metal in contact with high-temperature steam. The viscosity study has confirmed previous results, and the effect of stress on intercrystalline corrosion is being studied.

Fluid Meters (ASME, $1,000). Tests of discharge through various sizes of nozzles have been made at four university laboratories, and the National Bureau of Standards.

Lubrication (ASME, $1,000). It was decided to discontinue some activities and to take up others. Compilation of the lubrication bibliography is progressing. The subcommittee on viscosity at high rates of shear is studying its problem. The committee proposes to investigate temperature distribution in bearings and pedestals during the coming year.

Cottonseed Processing (ASME, $500). Work done in 1936–37 demonstrated that definite benefits accrue from short-time cooking of cottonseed under steam pressure at elevated temperatures; the work of 1937–38 included a practical application of the cooking process using small equipment.

Rolling Steels (ASME, $900). It has been decided to base the research made upon tension test specimens. The heating will be done in an induction furnace designed to operate at suitable temperatures. The design of a machine, which will draw out the specimens at the necessary rapid speeds of deformation, has been begun.

Stability of Impregnated-Paper Insulation (AIEE, $2,000 plus $1,000). The principal purpose of the research is a study of the dielectric strength and stability of impregnated-paper insulation as related to the density of the paper. The schedule of progress originally outlined for the work has been maintained, tests on four out of the five grades of paper to be tested have been completed. It is anticipated that no difficulty will be met in completing the tests on the five grades of paper before the date originally set for the completion of the experimental work. The supervisory committee has indicated that it considers the results to be of value and interest, and has considered generally a desirable program for a continuation of the work through another year.

Welding Research Committee (AIEE and American Welding Society, $4,000 plus $5,900). The work of the welding research committee is becoming an established, recognized institution. Leading articles and research reports carry bibliographic references to reports or reviews issued by the welding research committee. So far, the work has been concerned largely with critical digests of the literature, making available translations of important articles to research workers and others interested, and the conduct of relatively small, but important, pieces of fundamental research in leading universities. This year, however, has witnessed the financing of one of the major projects of the industrial research division, namely, the fatigue strength of welded joints. A fellowship was created at Rensselaer Polytechnic Institute in resistance welding, and grants-in-aid have been given to several selected universities for support of specific researches. During the year a total of 452 printed pages were published as *Research Supplements* to the *Welding Journal*. Thirty translations have been made available.

Engineers Council for Professional Development ($3,750). The major activity has been a continuation of the accrediting of institutions and curricula. An advisory service to institutions has been worked out in further detail, and already several opportunities have been developed of assisting institutions. Over 15,000 copies of "Engineering: A Career—A Culture" have been sold. More colleges are showing an interest in the problems of more careful selection of engineering freshmen.

Plastic Flow of Concrete (University of California, $1,500). During this year, the more important results have been in connection with the extensibility of concrete under temperature conditions simulating those existing in mass concrete as it heats and cools; the relation of the quality of hardened cement paste to flow; the relation of the quality of hardened cement to flow; the relation between moisture loss and flow; and the fiber strains due to flow in beams. Work is progressing on tests of the effect of thermal stresses in walls and slabs; the effect of revibration on plastic flow; the effect of sustained stress on bond between concrete and steel; the plastic flow of concrete in shear; and the plastic flow of concrete during the early hardening period.

Personnel Research Federation ($1,200). The problems incident to negotiations with employees have been studied by interviews with operating and industrial relations executives and labor leaders, studying records of negotiations and the literature on the subject. It is expected to publish the results of the study in a series of articles during the next months.

Wind Direction and Velocity (New York University, $500). Some experimental pilot balloon ascents with 180-degree cameras were made. Perfect recording occurred up to over 2,000 feet altitude. No higher as-

cents have been made. It appears likely that reliable readings will be obtained with the new apparatus at such altitudes as are required in pilot balloon work.

More complete progress reports on the active research projects are on file in the office of The Engineering Foundation. A number of specific problems are under investigation over a wide range of subjects rather than a small number of more elaborate problems. Further information on the Foundation and its activities may be obtained at Foundation's office, 29 West 39th Street, New York, N. Y.

Personal Items

F. B. Jewett (A'03, F'12) has been awarded the 1939 John Fritz Gold Medal, highest of American engineering honors, for "vision and leadership in science, and for notable achievement in the furtherance of industrial research and development in communication." The award is made annually for notable scientific or industrial achievement by a board composed of representatives of the four national engineering societies of civil, mining and metallurgical, mechanical, and electrical engineers. Doctor Jewett was born at Pasadena, Calif., September 5, 1879, and received the degrees of bachelor of arts (1898) from Throop Polytechnic Institute (now California Institute of Technology) and doctor of philosophy (1902) from the University of Chicago. From 1904 to 1912 he was associated with the American Telephone and Telegraph Company as transmission engineer, and in 1916 became chief engineer of the Western Electric Company after serving four years as assistant to that position. He was made vice-president of the Western Electric Company in 1922, and since 1925 has been vice-president in charge of development and research of the American Telephone and Telegraph Company and president of Bell Telephone Laboratories, Inc., in New York, N. Y. Doctor Jewett was awarded the AIEE Edison Medal in 1928, and the Washington Award of the Western Society of Engineers for 1938. The degree of doctor of science has been conferred upon him by six universities, and the degree of doctor of engineering by one; he also has received other honors. Doctor Jewett was vice-chairman of The Engineering Foundation from 1919 to 1925 and chairman of the division of engineering and industrial research of the National Research Council from 1923 to 1927. A past-president of the AIEE, he has been active in its work and in that of other societies of which he is a member. He was a member of the committee on railway research of the Science Advisory Board appointed by President Roosevelt, and is a director of the National Advisory Council on Radio in Education.

H. B. Bryans (M'17, F'18) has been elected executive vice-president of the Philadelphia Electric Company, Philadelphia, Pa. Mr. Bryans was born at Philadelphia March 26, 1886, and was graduated from the University of Pennsylvania in 1907 with the degree of bachelor of science in mechanical engineering. Following graduation he was connected with the Philadelphia Gas Works, Kansas City (Mo.) Gas Company, and Fulton County Gas and Electric Company, Gloversville, N. Y. In 1912 he returned to Philadelphia as assistant to inspecting engineer with the United Gas Improvement Company, and two years later was appointed engineer of the Counties Gas and Electric Company at Norristown, Pa. In 1927 he was made general superintendent of the Philadelphia Suburban-Counties Gas and Electric Company and in the following year was promoted to assistant general manager of the same company. Mr. Bryans was then transferred to the Philadelphia Electric Company and was made vice-president in 1929.

J. M. Conroy (A'23) has become deputy chief engineer of the Canadian Marconi Company, Montreal, Que., Canada. Mr. Conroy is a native (1886) of Ottawa, Ont., and a graduate of McGill University, from which he received the degree of bachelor of science in electrical engineering. He was employed by the Canadian Westinghouse Company, Canadian General Electric Company, and the Department of Naval Service before he joined the Canadian Marconi Company in 1922. Since that time he has steadily advanced in the company's services and has held the position of works engineer for the past 11 years.

R. E. Powers (A'33) has been appointed northwestern district service manager for the Westinghouse Electric and Manufacturing Company. Mr. Powers, who was graduated from Washington State College in 1923 with the degree of bachelor of science in electrical engineering, has been employed continuously by the Westinghouse company since 1923. In 1926 he was transferred to the central station division of general engineering, and was engineering representative in the New York district, being made eastern engineering manager in 1936.

F. W. Smith (A'18, M'34) has been appointed general engineer of the Virginia Electric and Power Company, Richmond. Born at Northampton, Mass., September 7, 1888, Mr. Smith received the degree of bachelor of science in electrical engineering from Worcester Polytechnic Institute. He obtained his first experience in the public utility field with the New England Power Company in 1913, acting in various capacities until 1919, where he accepted a position with the Goodyear Tire and Rubber Company, Akron, Ohio. The following year he entered the employ of the Stone and Webster Engineering Corporation at Boston, Mass., and in 1921 was transferred to the Blackstone Valley Gas and Electric Company at Pawtucket, R. I. In 1931 he became assistant general engineer for the Virginia Electric and Power Company. Mr. Smith is secretary of the AIEE Virginia Section.

M. M. Samuels (F'24) has resigned from the Federal Power Commission to accept appointment as chief operations engineer of the Rural Electrification Administration, Washington, D. C. Mr. Samuels joined the Federal Power Commission in 1934 as technical adviser of the electric rate survey and later as electrical engineer in the regional office at New York, N. Y. While with the commission he participated in the preparation of numerous confidential reports. A native of Schaki, Lithuania, he was graduated from the Technical University of Karlsruhe in 1905, and was for 20 years on the staff of the J. G. White Engineering Corporation where he was responsible for the electrical engineering of numerous utility and industrial projects.

R. E. Williams (A'35) has become a member of the staff of the technical press service of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. A native (1912) of Mulberry, Ind., and a graduate of Purdue University, from which he received the degree of bachelor of science in electrical engineering in 1934, Mr. Williams had been a member of the Institute's publication staff since 1936. Prior to joining the Institute's staff he was a member of the electrical-engineering staff of Gibbs and Cox, Inc., marine and naval architects

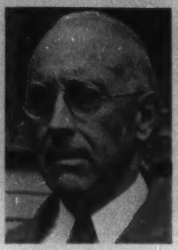
M. M. SAMUELS

H. B. BRYANS

F. B. JEWETT

C. F. SCOTT

FRANCIS HODGKINSON



JAMES DIXON

at New York, N. Y. He was a member of the AIEE Student Branch at Purdue, and is an associate, Society of Sigma Xi, national research honorary fraternity.

James Dixon (A'02, M'13) has accepted the position of assistant general manager and chief engineer with the Elliott Company, Ridgway, Pa. Mr. Dixon was born at New York, N. Y., March 5, 1877, and was graduated from Columbia University in 1901 with the degree of electrical engineer. He then entered the employ of the Gray National Telautograph Company for five years, and in 1910, following work with the General Storage Battery Company at Boonton, N. J., became superintendent of construction and repair with the Crocker Wheeler Company at Ampere, N. J. He returned to the company after a short absence in 1915 as assistant chief engineer. In 1920 he became production manager with the Reliance Electric and Engineering Company, Cleveland, Ohio. For the past several years Mr. Dixon had again been affiliated with the Crocker Wheeler Company as engineer of test, inspection, and construction.

C. F. Scott (A'92, F'25, HM'29) has been elected president of the National Council of State Boards of Engineering Examiners. Doctor Scott is emeritus professor of electrical engineering, Yale University, New Haven, Conn., and has recently been devoting much time to matters pertaining to education and registration of engineers. From 1935 to 1938 he was chairman of Engineers' Council for Professional Development, and for 1937–38 was vice-president of the NCSBEE. For 1938–39 he has been appointed chairman of the ECPD committee on professional recognition. Doctor Scott is a past-president of the AIEE and received the Edison Medal in 1929; he has a long record of service in Institute affairs.

Francis Hodgkinson (A'02) consulting mechanical engineer, New York, N. Y., has been awarded the Holley Medal of The American Society of Mechanical Engineers for "meritorious services in the development of the steam turbine." Mr. Hodgkinson is widely known as a designer and builder of steam turbines, and is honorary professor of mechanical engineering at Columbia University. He was born in London, England, June 16, 1867, and was educated in England. He was associated with C. A. Parsons in the early development of the reaction turbine, and was superintendent of construction of C. A. Parsons and Company when, in 1896, a license agreement was negotiated with the late George Westinghouse and Mr. Hodgkinson was given charge of steam-turbine construction for the Westinghouse Machine Company. In 1916 he was made chief engineer of the Westinghouse Electric and Manufacturing Company, and ten years later became consulting engineer for the company, serving in that capacity until his retirement in 1936. Stevens Institute of Technology granted him the honorary degree of mechanical engineer in 1934.

W. H. Rodgers (A'24, M'30) has been appointed engineering manager of the eastern district of the Westinghouse Electric Manufacturing Company, with headquarters at New York, N. Y. After graduating from the University of Illinois in 1922, Mr. Rodgers entered the central station engineering section of the Westinghouse company at East Pittsburgh, Pa., and for nearly 15 years, until his present appointment, worked on electrical supply and distribution problems.

F. H. Doremus (A'24, M'32) has been appointed manager for the Rocky Mountain district of the transportation department of the General Electric Company at Denver, Colo.; he also is manager of the industrial department for that district. Mr. Doremus has been affiliated continuously with the company since graduation from the University of Nebraska in 1922, and was transferred to the industrial department at Denver in 1925.

W. H. Harrison (A'20, F'31) has been elected a member of the corporation of the Polytechnic Institute of Brooklyn. Vice-president and chief engineer of the American Telephone and Telegraph Company, New York, N. Y., he is a past president of the AIEE, and recently was granted the honorary degree of doctor of engineering as announced in the July 1938 issue.

Zay Jeffries (M'36) has been elected a member of the corporation of Case School of Applied Science, Cleveland, Ohio. Doctor Jeffries was a member of the faculty of the school from 1911 to 1917, and is an authority in metallurgy. He is now technical director of the incandescent lamp department of the General Electric Company at Cleveland.

B. S. Rodey, Jr. (A'22, M'26) has received the degree of doctor of judicial science after writing a thesis on the terms "original cost" and "prudent investment." Mr. Rodey is auditor with the Consolidated Edison Company of New York, Inc., New York, N. Y., and chairman of the general accounting committee of the Edison Electric Institute.

R. E. Doherty (A'16, M'27) has been elected vice-chairman of Engineers' Council for Professional Development for the year 1938–39. Doctor Doherty is president of Carnegie Institute of Technology, Pittsburgh, Pa., and is the recipient of the 1937 Lamme Medal, as announced on page 141 of the March 1938 issue.

J. H. Foote (A'18, F'32) has been elected chairman of the committee on copper and copper alloy wires for electrical conductors of the American Society for Testing Materials. Mr. Foote is supervising engineer with the Commonwealth and Southern Corporation, Jackson, Mich.

S. H. P. Wolferstan (M'35) has been appointed manager of the contract service department of the Canadian General Electric Company, Toronto, Ont. He formerly was district engineer for the company at Montreal, Que.

G. G. Post (A'11, F'33) has been elected president of the Engineers' Society of Milwaukee. Mr. Post is vice-president in charge of power, Milwaukee Electric Railway and Power Company, Milwaukee, Wis.

D. E. Culnan (A'37) has accepted a position as junior examiner in the electrical engineering division of the United States Patent Office at Washington, D. C. Mr. Culnan formerly was junior engineer with Fibreboard Products, Inc., Antioch, Calif.

Douglas Montgomery (A'26) has accepted a position as assistant electrical engineer with the Illinois Iowa Power Company, Champaign, Ill. Formerly he was electrical draftsman with the Detroit Edison Company, Detroit, Mich.

Norman Carlberg (A'38) is now junior engineer with the United States Navy Yard at Bremerton, Wash. He formerly was at Fort Peck, Mont.

J. R. Read (A'04) recently was elected a director of the Canadian Westinghouse Company, Hamilton, Ont. He is vice-president of the company.

E. J. Withers (A'34) now is employed in plant operations work for Hiram Walker and Sons, Inc., Peoria, Ill.

F. W. Frink (A'31) has become a radio engineer for the Radio Receptor Company, New York, N. Y.

L. E. Mathews (A'35) has been appointed assistant rate analyst for the Rural Electrification Administration, Washington, D. C.

W. J. Lind (A'36) has become an air conditioning engineer for the Canadian General Electric Company, Ltd., Vancouver, B. C.

E. H. Small (A'38) has been appointed instructor in mechanical engineering at the University of Toledo (Ohio).

Obituary

Walter Sherman Moody (A'06, M'10, F'12) retired transformer engineer, died November 7, 1938, at Pittsfield, Mass. Born at Chelsea, Mass., September 20, 1864, Mr. Moody in 1887 was a member of the first electrical-engineering class to graduate from Massachusetts Institute of Technology. He remained for one year as instructor, a period during which he met William Stanley at a demonstration of an a-c system and was impressed with the possibilities of a-c distribution. In 1888 Mr. Moody became assistant engineer of the Thomson Electric Welding Company, and in 1892 joined the staff of the Thomson-Houston Electric Company at Lynn as designing engineer in transformers and a-c dynamos. In that year the company merged with the General Electric Company and Mr. Moody was made chief engineer of the transformer department at Lynn. He was transferred to Schenectady, N. Y., in the same capacity in 1897, and in 1908 was placed in charge of transformer engineering for the entire company at Pittsfield. In 1927 he was named consulting engineer by the company, and in 1931 he retired from active work. Mr. Moody contributed many improvements in transformers and induction regulators, and did pioneer work in the use of silicon sheet steel in electrical equipment. He was one of the original members of the Institute's Pittsfield Section, and at one time was a representative on the United States National Committee of the International Electrotechnical Commission.

S. Clifford Jacoby (A'21, M'31) superintendent of transmission and distribution, Montaup Electric Company, Fall River, Mass., died October 20, 1938. Mr. Jacoby was born at Conshohocken, Pa., August 21, 1896, and was graduated from a course in engineering in 1917. He then accepted the position of student engineer with Stone and Webster, and was sent to Key West, Fla. Two years later he was transferred to the Blackstone Valley Gas and Electric Company at Pawtucket, R. I., where he was promoted through several positions. In 1925 he was made chief load dispatcher for the Montaup Electric Company, and three years later was promoted to the position of superintendent of transmission and distribution.

Harold Hutchison Shearer (M'20) directory engineer, American Telephone and Telegraph Company, New York, N. Y., died November 10, 1938. Mr. Shearer was born at Bay City, Mich., August 24, 1886, and studied at the University of Michigan, from which he was graduated in 1908 with the degree of bachelor of science in electrical engineering. He was then employed in the Long Island division of the New York Telephone Company, and in 1913 became division plant engineer. During 1917–19 he served as major and lieutenant colonel with the United States Army in France, and shortly after his return to the United States was transferred to the general engineering staff of the operations section of the American Telephone and Telegraph Company at New York. He had been directory engineer for the past ten years. Mr. Shearer was a member of Sigma Xi and Tau Beta Pi.

Kenneth Buchanan Thornton (A'01, M'13) general manager of Montreal Tramways Company, Montreal, Que., Canada, died February 10, 1938. He was born at Montreal June 26, 1873, and studied electrical and mechanical engineering at Central Technical College, London, England. From 1893 to 1895 he was associated with the Royal Electric Company and the Montreal Light, Heat and Power Company at Montreal, following which he became associated with J. G. White and Company, having various operating positions with companies in New York, Portland, Me., and Connecticut. In 1911 Mr. Thornton became chief engineer and operating manager for the Canadian Light and Power Company and its affiliated companies, in 1920 general manager of the Montreal Public Service Corporation, and in 1926 of the Montreal Tramways Company.

George Herbert Thrush, Jr. (A'34) manager of the Pittsburgh, Pa., branch of The Electric Storage Battery Company, died September 25, 1938. Mr. Thrush was a native of Shippensburg, Pa., where he was born September 25, 1894. From 1911 to 1919 he served in the United States Army, rising to the rank of captain and later becoming major in the Officers Reserve Corps. In 1919 he entered Gettysburg College, from which he was graduated in 1924 with the degree of bachelor of science in electrical engineering. For brief periods he was employed by the Bell Telephone Company of Pennsylvania; in 1924 he became sales engineer with The Electric Storage Battery Company. He held various positions in offices at Atlanta, Ga., New Orleans, La., and Pittsburgh, being appointed manager of the last branch in 1930.

Hugo P. Geisler, Jr. (M'36) appraisal manager, Stone and Webster Engineering Corporation, Boston, Mass., died September 10, 1938. Born at Saginaw, Mich., June 29, 1895, Mr. Geisler studied electrical engineering at Massachusetts Institute of Technology. In 1918 he joined the Stone and Webster organization, and subsequently held various positions in gas and electric companies operating in the states of Kentucky, Connecticut, Washington, and Louisiana. In 1927 he was made engineer in the appraisal division of the organization, and following several other advances was made appraisal engineer in 1930. Three years later he was given the title of appraisal manager and personal responsible charge of general appraisal work of the company involving properties having a value in excess of one billion dollars.

James P. Alexander (M'21) New England district manager for the Westinghouse Electric and Manufacturing Company, Boston, Mass., died October 8, 1938. He was born at Chambersburg, Pa., November 22, 1885, and was graduated from Lafayette College with the degree of electrical engineer in 1907. In that year he entered the employ of the Westinghouse company, and after completing the apprentice course entered the railway department at East Pittsburgh, Pa., remaining there until 1911 when he was transferred to the Boston office as railway engineer. In 1913 he became a railway salesman located in the Springfield, Mass., office and two years later went to the New Haven, Conn., office as railway and central station salesman. He was made manager of the transportation division at Boston in 1922 and manager of the New Haven branch office in 1924, returning to Boston ten years ago as manager in charge of all sales and service in New England.

Frederick Miles Bronson (M'36) engineer with the American Telephone and Telegraph Company, Washington, D. C., died October 23, 1938. Mr. Bronson was born at Walton, N. Y., May 11, 1882, and became manager of the Walton Telephone Company in 1900. Two years later he entered the engineering department of the New England Telephone and Telegraph Company at Boston, Mass., at subsequently held positions at Bangor and Portland, Me. In 1910 he became engineer in the engineering department of the American Telephone and Telegraph Company at New York, N. Y., where he had increasing responsibility in traffic engineering and operating problems. Mr. Bronson was transferred to Washington two years ago.

Watkins Franklin Mintzer (A'20) retired construction engineer, service department, Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada, died August 22, 1938. Mr. Mintzer was born at Croydon, Pa., December 3, 1889, and in 1908 entered the employ of a company manufacturing scientific instruments; after a short time he joined the Metropolitan Railway Company in New York, N. Y. In 1910 he accepted a position with the General Electric Company, and two years later became engaged in electrical construction work with the Canadian Westinghouse Company, an affiliation which he continued until his retirement in 1934.

James L. F. Bracken (A'18) designing engineer, New York, New Haven and Hartford Railroad Company, New York, N. Y., died October 21, 1938. Mr. Bracken was born October 10, 1893, and studied engineering at the Sheffield Scientific School of Yale University. In 1915 he entered an apprentice course in the electric locomotive shops of the New Haven Railroad, and two years later was made electrical draftsman. He became assistant electrical engineer in 1920, and in 1928 was transferred to New York as assistant to mechanical superintendent. A few years later he was made designing engineer.

Charles H. Harris (A'34) general engineer of the Virginia Electric and Power Company, Richmond, died October 22, 1938. He was born at Natick, Mass., and received the degree of bachelor of science from Massachusetts Institute of Technology in

1901. Upon graduation he joined the Stone and Webster organization at Boston, Mass., and subsequently held various positions with the Seattle Electric Company, Minneapolis General Electric Company, Mississippi River Power Company, Western United Company, and Tampa Electric Company. Mr. Harris had been with the Virginia Electric and Power Company since 1927.

Arnold Simeon Upley (A'37) electrical engineer, Chase-Shawmut Company, Newburyport, Mass., died recently. He was born at Roxbury, Mass., August 16, 1913, and received the degree of bachelor of science in electrical engineering from Northeastern University in 1936. As a cooperative student he was employed by The Edison Electric Illuminating Company of Boston in 1931–32, and in 1936 he entered the engineering department of the Chase-Shawmut Company where he was engaged in design and research on fuses.

Gisle Edwin Huseby (A'26) engineer, Illinois Bell Telephone Company, Chicago, died October 2, 1938. He was born at New Richland, Minn., November 27, 1898, and was graduated from the University of Minnesota with the degree of bachelor of science in electrical engineering in 1924. In that year he entered the employ of the Western Electric Company at Chicago as equipment engineer; a short time later Mr. Huseby became associated with the Illinois Bell Telephone Company.

Montgomery Ralston Bird (A'36) tester, General Electric Company, Bloomfield, N. J., died November 27, 1936, according to word just received at Institute headquarters. Mr. Bird was born at North Plainfield, N. J., December 29, 1910, and was graduated from the Newark College of Engineering in 1935 with the degree of bachelor of science in electrical engineering. Early in 1936 he entered the employment of the General Electric Company as a tester in the air-conditioning department.

Raymond Guttmann (A'35) Albany, N. Y., died February 22, 1938. Mr. Guttmann was born at Schoharie, N. Y., August 30, 1911, and was graduated from Rensselaer Polytechnic Institute in 1934 with the degree of electrical engineer.

Membership

Recommended for Transfer

The board of examiners, at its meeting on November 17, 1938, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Piatt, Wm. M., consulting engineer, Durham, N. C.
Race, H. H., research engineer, General Electric Company, Schenectady, N. Y.

2 to Grade of Fellow

To Grade of Member

Fies, John, assistant to head of distribution department, Dallas Power & Light Company, Dallas, Texas
Ghen, M. W., superintendent, downtown division, Duquesne Light Company, Pittsburgh, Pa.
Janes, C. W., instructor in electrical engineering, University of Arkansas, Fayetteville.
Maxfield, F. A., instructor in electrical engineering, University of Wisconsin, Madison.
Nuesel, E. F., superintendent, underground electrical transmission and distribution department, Cincinnati Gas & Electric Company, Cincinnati, Ohio
Sessoms, O. V. P., superintendent, meter and installation department, Virginia Electric & Power Company, Richmond, Va.
Sixtus, E. F., vice-president in charge of sales, Pacific Electric Manufacturing Corporation, San Francisco, Calif.
Sturtevant, G. R., meter engineer, General Electric Company, West Lynn, Mass.

2 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1938, or February 28, 1939, if the applicant resides outside of the United States or Canada.

United States and Canada

Abraham, L. G. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Arning, H. U., Otis Elevator Company, New York, N. Y.
Austry, W. H. (Member), Stackpole Carbon Company, St. Marys, Pa.
Balacek, F. P., Bell Telephone Laboratories, Inc., New York, N. Y.
Booth, R. H., Worthington Pump and Machinery Corporation, Seattle, Wash.
Bunten, G. E., Bureau of Power and Light, Los Angeles, Calif.
Carter, C. W., Jr. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Christensen, E. F., General Electric Company, Pittsfield, Mass.
Clemens, G. J., City College of New York, New York, N. Y.
Clements, S. E., Iowa State College, Ames.
Cookman, F. W., Portland General Electric Company, Portland, Ore.
Couch, W. H., Hickok Electrical Instrument Company, Cleveland, Ohio.
Davis, J. I. (Member), Commonwealth Edison Company, Chicago, Ill.
de Carvajal, C. A. R., National Broadcasting Company, New York, N. Y.
Diller, H. N., Ohio Public Service Company, Mansfield.
Dillon, H. M., Nelson Electric Supply Company, Oklahoma City, Okla.
Dlouhy, F. S., Oklahoma Gas and Electric Company, Oklahoma City.
Doolittle, J. W., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Dwyer, R. C., Bonneville Project, Portland, Ore.
Ennis, J. G., Florida Power and Light Company, Miami.
Gandy, T. O., Oklahoma Gas and Electric Company, Ardmore.
Gartner, H. C., Cincinnati Gas and Electric Company, Cincinnati, Ohio.
George, E. L., Southern Bell Telephone and Telegraph Company, New Orleans, La.
Glidewell, J. A., Western Union Telegraph Company, Dallas, Texas.
Greenleaf, E. R., The Chesapeake and Potomac Telephone Company, Washington, D. C.
Griffin, W. H. (Member), Southwestern Creosoting Company, Muskogee, Okla.
Hachemeister, C. A., City College of New York, New York, N. Y.
Hall, E. R., General Electric X-Ray Corporation, San Francisco, Calif.
Harding, W. K., Duke Power Company, Charlotte, N. C.
Hartman, T. W., Cleveland Public Schools and Fenn College, Cleveland, Ohio.
Haynes, H., General Electric Company, Cleveland, Ohio.
Hayward, H. O. F., British Columbia Electric Railway Company, Vancouver, B. C., Canada.
Hendricks, R. M., Southern New England Telephone Company, New Haven, Conn.
Hinshaw, E. C., Indiana Bell Telephone Company, Indianapolis.
Hobbs, W. E., Chesapeake and Potomac Telephone Company, Richmond, Va.
Hofer, H. T., Public Service Company of Colorado, Denver.
Hoover, J. W., International Business Machines Corporation, Endicott, N. Y.
Jahn, E., J. G. White Engineering Corporation, New York, N. Y.
King, R. E., Consolidated Edison Company of New York, Inc., New York, N. Y.
Kraus, C. R., Bell Telephone Company of Pennsylvania, Philadelphia.
LaDieu, W. L., Delgado Central Trades School, New Orleans, La.
Limpus, L. M., Oklahoma Gas and Electric Company, Oklahoma City.
Llewellyn, M. R., Southern Utah Power Company, Cedar City, Utah.
Mackie, F. W., Southwestern Light and Power Company, Lawton, Okla.
Million, B. J., Southwestern Light & Power Company, Clinton, Okla.
Moench, T. S., American Telephone and Telegraph Company, Buffalo, N. Y.
Morningstar, M. B., E. 2013 Mallon Avenue, Spokane, Wash.
Moses, B. S., Pacific Gas and Electric Company, San Francisco, Calif.
Muir, W. L., Nelson Electric Supply Company, Oklahoma City, Okla.
Neal, B. F., Southwestern Light and Power Company, Lawton, Okla.
Nichols, C. E., Tennessee Valley Authority, Knoxville, Tenn.
Nicholson, A. J., Kansas City Power and Light Company, Kansas City, Mo.
Patterson, J. McG., Delgado Trade School, New Orleans, La.
Pearman, M. N., Chesapeake and Potomac Telephone Company, Richmond, Va.
Pickrell, D. H., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Pierce, H. F. (Member), Maurice H. Connell and Associates, Miami, Fla.
Poillion, C. B., Delgado Central Trades School, New Orleans, La.
Plumley, H. J., Commonwealth Edison Company, Chicago, Ill.
Roth, J. D., Ohio Carbon Company, Cleveland.
Rubel, W. L. (Member), Memco Engineering and Manufacturing Co., Long Island City, N. Y.
Rudden, F. J., Memco Engineering and Manufacturing Company, Inc., Long Island City, N. Y.
Ryan, J. A. (Member), 4 Irving Place, New York, N. Y.
Schricker, J. L., General Electric Supply Corporation, Salt Lake City, Utah.
Schwarz, J., Brooklyn Edison Company, Brooklyn, N. Y.
Secord, R. E., Narragansett Electric Company, Providence, R. I.
Simmons, R. P., Cowles and Company, Dallas, Texas.
Snider, F. C., Hickok Electrical Instrument Company, Cleveland, Ohio.
Steck, H. L., Southern California Edison Company Ltd., Long Beach, Calif.
Taylor, J. J. (Member), Detroit Edison Company, Detroit, Mich.
Thomas, G. B., Jr., New York University, New York, N. Y.
Thomson, R. B., Henderson County Rural Electric Association, Henderson, Ky.
Vanoli, J. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Walton, A. W., Oklahoma Gas and Electric Company, Oklahoma City.
Wells, C. H., General Electric Co., Pittsfield, Mass.
Wheeler, W. R. (Member), American Telephone and Telegraph Company, Philadelphia, Pa.
Whitehouse, A. B. (Member), Lynn Gas and Electric Company, Lynn, Mass.
Withington, W. G., General Electric Company, Baltimore, Md.
Wittenburg, H. W., Sangamo Electric Company, Los Angeles, Calif.
Zabaro, D., Bureau of Power and Light, Los Angeles, Calif.

Total, United States and Canada—79

Elsewhere

Chakraverty, N. C., Nowrosjee Wadia College, Poona, India.
Currie, J. A. (Member), C. A. Sothers Ltd., Bham, England.
Dubuse, R. P. (Member), Cie. pour la Fabrication des Compteurs, Montrouge (Seine), France.
Jain, I. D., The British Insulated Cables Ltd., Calcutta, India.
Krishnaswami, P., C. N. Technical Institute, Madras, India.
Porter, J. H., Metropolitan Vickers Company Ltd., Manchester, England.
Ratnasabapathy, V., 86 Central Avenue, Calcutta, India.
Warder, S. B. (Member), Southern Railway Company Waterloo, London, England.

Total elsewhere—8

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Barrett, Earl J., Don Pedro Dam, La Grange, Calif.
Black, Kenneth H., 916 Yale Ave., S., Seattle, Wash.
De Lay, R. E., 77 Prospect Ave., Long Beach, Calif.
Gademann, Oscar M., Stuttgarterplatz 1A-11 Berlin-Charlottenburg, Germany
Hutchison, Paul C., 529 N. 13th St., Milwaukee, Wis.
Hyman, Stanley L., 156 Medway St., Providence, R. I.
Kapell, Sidney M., 3043 Emmons Ave., Brooklyn, N. Y.
Phillips, Cary Albert, Box 80-A, Route 6, Richmond, Va.
Platterer, Alvin, 776 N. Cass St., Milwaukee, Wis.
Robison, R. L., 941 E. Northlake Ave., Seattle, Wash.
Shimp, Robert P., 414 Hampton Ave., Wilkinsburg, Pa.
Whitney, T. G., Electrical Research Products, Inc., 250 W. 57th St., New York, N. Y.
Wilson, Alexander, 315 New Birks Bldg., Montreal, Que., Can.

13 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

DEMONSTRATION EXPERIMENTS in PHYSICS. Edited by R. M. Sutton, prepared under the auspices of the American Association of Physics Teachers. New York and London, McGraw-Hill Book Company, 1938. 545 pages, illustrated, 9 by 6 inches, cloth, $4.50. A collection of lecture experiments for the use of high school and college teachers of physics and general science.

TRANSFORMER ENGINEERING. By L. F. Blume, G. Camilli, A. Boyajian and V. M. Montsinger; edited by L. F. Blume. New York, John Wiley and Sons, 1938. 496 pages, diagrams, charts, tables, 9 by 6 inches, cloth, $5.00. Designed to assist engineers in the specification, selection, application, and operation of transformers. Emphasizes the essential physics of each problem.

TRANSFORMATOREN mit STUFENREGELUNG UNTER LAST. By A. Böhne and R. Küchler. Munich and Berlin, R. Oldenbourg, 1938. 182 pages, illustrated, 10 by 6 inches, cloth, 9.60 rm. Discusses the theory, construction, and use of transformers equipped with tap changers.

ENGINEERING MECHANICS. By S. Fairman and C. S. Cutshall. New York, John Wiley and Sons, 1938. 267 pages, diagrams, tables, 9 by 6 inches, cloth, $2.75. Presents only as much material as can be covered conveniently in a basic course. Contains the customary treatment of statics and kinetics, numerous problems being included.

DECIBELS and PHONS, a Musical Analogy. By L. S. Lloyd. London, New York, and Toronto, Oxford University Press, 1938. 18 pages, tables, 9 by 6 inches, paper, $0.50. An explanation of the meaning of the terms "phon" and "decibel" by considering the phon as a loudness-interval, comparable to the musical interval of a major third, and the decibel as representing the energy-interval which produces the phon.

BIBLIOGRAPHY on INDUSTRIAL RADIOGRAPHY. -(Document 1139.) By H. R. Isenburger. Washington, D. C., American Documentation Institute, 1938. 52 pages, typewritten, 12 by 9 inches, paper, $0.72 in microfilm, or $3.32 in black and white prints. Supplement to St. John and Isenburger's book, "Industrial Radiography"; contains 776 references, arranged chronologically, covering material from early 18th century general theory to recent applications.

ATOMIC STRUCTURE. By L. B. Loeb. New York, John Wiley and Sons, 1938. 446 pages, illustrated, 9 by 6 inches, cloth, $4.50. Intended to supplement a basic course in physics and to provide students who have a working knowledge of calculus with a thorough grounding in atomic structure.

APPLIED MECHANICS. By H. F. Girvin. Scranton, Pa., International Textbook Company, 1938. 336 pages, diagrams, tables, 9 by 6 inches, cloth, $3.00. So arranged that the chapters covering graphical solutions may be used as a text for a course in graphic statics, being segregated from the purely mathematical treatment.

ADVANCED MATHEMATICS for ENGINEERS. By H. W. Reddick and F. H. Miller. New York, John Wiley and Sons, 1938. 473 pages, diagrams, charts, tables, 9 by 6 inches, cloth, $4.00. Discusses differential equations, vector analysis, probability, operational calculus, and the more complex mathematical functions and series, emphasis being placed on physical applications by illustrating each principal topic by problems relating to civil, electrical, mechanical, and chemical engineering.

WIRELESS SERVICING MANUAL. By W. T. Cocking. Fourth revised edition. London, The Wireless World, Iliffe and Sons, Ltd., 1938. 278 pages, illustrated, cloth, 5s. 5d. Covers the principles and practice of the repair and adjustment of wireless receivers. A chapter is devoted to television receivers.

VDI-JAHRBUCH 1938. Die Chronik der Technik, edited by A. Leitner of VDI. Berlin, VDI-Verlag, 1938. 312 pages, 8 by 6 inches, paper, 3.50 rm. Contains nearly 100 reports on developments during 1937 in various branches of engineering and technology.

TECHNICAL PROGRESS and UNEMPLOYMENT. Studies and Reports, Series C (Employment and Unemployment) No. 22. By E. Lederer. Geneva, Switzerland, International Labor Office, 1938. 267 pages, tables, 10 by 7 inches, paper, $1.50 (obtainable from United States branch, Washington, D. C.). An analysis of the social and economic effects of technical progress, especially on unemployment and the formation of capital. Discusses the various forms of technical progress, the concept of technological unemployment, increasing and diminishing returns, the equilibrium of the labor market, the effects of technical progress on the economic system and the labor and capital market, the elasticity of modern monetary systems, technical improvements and the business cycle, and capital-saving technical improvements.

(The) SCIENCE of PRODUCTION ORGANIZATION. By B. H. Anderson and G. T. Schwenning. New York, John Wiley and Sons, 1938. 282 pages, 9 by 6 inches, cloth, $3.50. Devoted mostly to the physical organization of work through operation study or job analysis and to the various types of organization of workers within small departments, plants, or whole enterprises. Discusses briefly larger aspects of the production problem.

RADIO LABORATORY HANDBOOK. By M. G. Scroggie. London, Wireless World, Iliffe and Sons, 1938. 384 pages, illustrated, 8 by 5 inches, cloth, 8s. 6d. Prepared with special consideration of the needs of amateurs and laboratory workers. Discusses fundamental principles, sources of power and signals, measurements, and certain specialized types of work, such as ultrahigh frequency.

PHOTOELECTRIC CELL APPLICATIONS. By R. C. Walker and T. M. C. Lance. Third edition. New York and Chicago, Pitman Publishing Corporation, 1938. 336 pages, illustrated, 9 by 6 inches, cloth, $4.00. Restricted to discussion of the alkali-metal cell (with some reference to the rectifier cell). Describes the circuits used in counting and handling devices, alarms, sound reproduction, phototelegraphy, television, and miscellaneous applications.

MARCONI, the Man and His Wireless. By O. E. Dunlap, Jr. Revised edition. New York, Macmillan Company, 1938. 362 pages, illustrated, 9 by 6 inches, cloth, $3.50. The life of Marconi is portrayed against the background of his invention. The resulting biography constitutes a history of radio as well.

ENGINEERING TERMINOLOGY. Definitions of Technical Words and Phrases. By V. J. Brown and D. G. Runner. Chicago, Gillette Publishing Company, 1938. 310 pages, illustrated, diagrams, 9 by 6 inches, cloth, $3.50. A list of terms often used in technical writing and specifications, with definitions obtained from the usage of various trade and engineering organizations. The terms apply especially to civil engineering and architecture. Contains also a concise Spanish-English and English-Spanish dictionary of highway terms, a brief German-English dictionary of terms for mineral aggregates, and several tables of technical symbols, abbreviations, and conversion factors.

ELECTROMAGNETICS. By A. O'Rahilly, with a foreword by A. W. Conway. London, New York, and Toronto, Longmans, Green, and Company, 1938. 894 pages, diagrams, tables, 9 by 6 inches, cloth, $12.50. A critical review of the classical theory of electricity, discussing fundamentals, and the work of the men who have had an important influence on the thought and action in this field of physics. Contains two chapters in which a radical exposition of the meaning of the symbols of physics is worked out and the question of basic units and dimensions is discussed.

ELECTRIC POWER CIRCUITS, Theory and Applications. Volume 2. POWER SYSTEM STABILITY. By O. G. C. Dahl. New York and London, McGraw-Hill Book Company, 1938. 698 pages, diagrams, charts, tables, 10 by 6 inches, cloth, $7.00. Contains several chapters on each of the following topics: steady-state power limits, steady-state stability and transient stability, considering carrying conditions and different methods of analysis. Other chapters cover load characteristics, circuit equations for faulted networks, exciter analysis, damper windings, inertia, and grounding.

EDISON'S OPEN DOOR. By A. O. Tate. New York, E. P. Dutton and Company, 1938. 320 pages, 9 by 6 inches, cloth, $3.00. An informal account of Edison during one of the most dramatic periods of his life, based upon personal knowledge. Many other interesting characters and events are discussed.

DIRECT-CURRENT MACHINERY. By T. C. McFarland. Scranton, Pa., International Textbook Company, 1938. 439 pages, diagrams, charts, tables, 9 by 6 inches, leather, $4.00. Physical pictures of the assemblies are first presented, then operating characteristics and control, proceeding from no-load characteristics to load characteristics are discussed. Material on the no-load saturation curve and armature reaction is included.

GASEOUS ELECTRICAL CONDUCTORS. By E. L. E. Wheatcroft. Oxford, England, Clarendon Press; N. Y., Oxford University Press, 1938. 265 p., illus., 10 by 6 in., cloth, 21s. $6.50 U.S.A. For the technical man interested in vacuum tubes and similar apparatus; discusses first the fundamental facts of atomic structure, ionization, and emission. Succeeding chapters cover modern views on the nature of glow, corona, arc and spark, and final chapters deal with the application of the principles to various types of apparatus, such as vacuum and gas-filled tubes, rectifiers, circuit-breakers, and lamps.

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☐ 38-40	McEachron	*Multiple Lightning Strokes—II
☐ 38-41	Lennox & DeBlieux	*A Direct-Current Transformer
☐ 38-42	LaPierre & Mansfield	*Photoelectric Weft-Straightener Control
☐ 38-44	Sporn & Gross	*Protector-Tube Application and Performance on 132-Kv Lines—II
☐ 38-45	Brosnan	*System Planning and Operation for Voltage Control
☐ 38-46	Benner & Lunge	*Voltage-Regulating-Equipment Characteristics
☐ 38-47	Landis	*Voltage Regulation and Control of Rural Lines
☐ 38-48	Burrell & Appleton	*The Periodic Voltage Survey as a Basis for Distribution Design
☐ 38-49	Rogers	*Regenerative Tension Control for Paper Winders
☐ 38-50	Bendz	*Comparison of Methods of Stopping Squirrel-Cage Induction Motors
☐ 38-51	Von Sothen	*The Application of Capacitors in Industrial Plants
☐ 38-52	Vogel	*Corona Voltages of Typical Transformer Insulation

Papers Presented at Summer Convention, Washington, D. C., June 20–24, 1938

☐ 37-58	Smith & Weygandt	*Double Line-to-Neutral Short Circuit of an Alternator
☐ 37-86*	Appleman	*The Cause and Elimination of Noise in Small Motors
☐ 38-53	Calvert	Amplitudes of the MMF Harmonics for Fractional Slot Windings
☐ 38-54	Porter	*Positive-Grid Characteristics of Triodes
☐ 38-55	Bewley	Traveling Waves Initiated by Switching
☐ 38-56	Subcommittee Report	*Line-Type Lightning-Arrester Performance Data
☐ 38-58	Whitehead	*Lightning Protection of 22-Kv Substations
☐ 38-59	Poritsky	Graphical Field-Plotting Methods in Engineering
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☐ 38-63	Champe & Von Voigtlander	*System Analysis for Petersen Coil Application
☐ 38-64	Gulliksen	*A Position Regulator for Paper Slitters
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☐ 38-111	Cossens	Insulation and Lightning Protection
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☐ 38-118	Pierce and Hamilton	Phase-Angle Control of System Interconnections
☐ 38-119	Lyon	The Electrostatic Unbalance of Transmission Lines

* These papers have been published in the TRANSACTIONS section of ELECTRICAL ENGINEERING.

Transactions

Papers and Discussions Comprising Pages 663–712 of the 1938 Volume

System Analysis for Petersen-Coil Application

By W. C. CHAMPE
MEMBER AIEE

F. VON VOIGTLANDER
MEMBER AIEE

Synopsis: Careful analysis of the characteristics of a power system has been found to be necessary before applying Petersen coils to a system which has been operating either with the neutral isolated or grounded. In these two companion papers on Petersen coils, accent has been placed on the analysis of system characteristics in order to determine whether or not the application of Petersen coils will be satisfactory.

In this paper (part I) the general features of Petersen-coil application are considered, and the fundamentals of calculating coil characteristics are given. In the companion paper (part II) by F. Von Voigtlander, the methods of performing detailed calculations on system fault currents, coil ratings, and voltages are given in an illustrative example, together with field tests to check design computations and performance of the equipment.

Part I—Operating Features and Basic Calculations—By W. C. Champe

Introduction

CONSIDERABLE interest has recently been shown in this country in the application of resonant neutral grounding reactors, or Petersen coils, to medium- and high-voltage transmission systems for the purpose of extinguishing single line-to-ground faults without the operation of circuit breakers and before they spread to phase-to-phase or three-phase short circuits. Applications have been made of Petersen coils to existing systems, most of these having been systems which were originally operated with the neutral isolated, since adequate relaying of single line-to-ground faults is ordinarily more difficult to obtain on an isolated-neutral system than on a grounded-neutral system.

A Petersen coil usually consists of a tapped inductance with iron core, connected between ground and the neutral point of a suitable transformer bank so that, in the case of an arc to ground of one conductor of the transmission system, the total reactive lagging current from the coils will be approximately equal to the residual charging current to ground of the system. The inductive reactance of the system, most of which will be in the Petersen coil or coils, will then be approximately equal to the capacitive reactance of the two unfaulted conductors to ground. If the coils are properly tuned, the fault current in a single phase-to-ground fault will be principally the in-phase component, which cannot be balanced out by the coils and ordinarily will be so low that the arc will be self-extinguishing.

Paper number 38-63, recommended by the AIEE committee on protective devices and presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938. Manuscript submitted March 21, 1938; made available for preprinting May 19, 1938.

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These papers (parts I and II) are based on a study of Petersen-coil application and operation over a period of years, and the authors wish to express acknowledgment of the suggestions given by their associates, in particular to Mr. J. R. North for his encouragement and assistance.

Effects on System Operation

Following is an outline of the effects on system operation to be expected from the installation of Petersen coils as compared to isolated-neutral and grounded-neutral systems:

Ground-Fault Current Magnitude

1. On most grounded-neutral systems in this country, the ground-fault currents are quite large.

2. On an isolated-neutral system, the current through a single line-to-ground fault depends upon the length of transmission lines, and with an extensive system is large enough to maintain an arc.

3. On Petersen-coil systems, when properly tuned, the ground-fault current is reduced to a relatively small value, approximately the in-phase component of residual current. Damage to the equipment at the point of fault, due to current, is therefore greatly reduced. More thorough consideration of current magnitudes is given in a later part of this paper.

Ground-Fault Elimination

1. On grounded-neutral systems, all types of ground faults ordinarily cause trip-outs.

2. On all isolated-neutral systems, unless small in extent, single-phase faults to ground are not self-extinguishing. Since these faults are difficult to relay properly, they may continue until they become two-phase or three-phase faults and the section of line is relayed out.

3. On a system to which Petersen coils can be successfully applied, practically all transitory single-phase faults are self-extinguishing before developing into two-phase or three-phase faults. Relay operations and interruptions to service, therefore, should be much reduced by the installation of Petersen coils on either a grounded-neutral or isolated-neutral system.

Maximum Line-to-Ground Voltages

1. Grounded-neutral systems in this country usually have sufficiently low values of neutral grounding resistance or reactance that the neutral at all parts of the system does not vary greatly from ground potential. Line-to-ground voltages on the unfaulted phases, therefore, do not increase greatly during fault conditions.

2. On isolated-neutral systems, line-to-ground voltages on the unfaulted phases at the point of fault are approximately equal to line-to-line voltages, and at distant points may be 20 to 50 per cent greater. In some cases, this may result in a double line-to-ground fault.

3. With one Petersen coil, overvoltages for faults at most locations would be lower than on an isolated-neutral system, and equipment would be less likely to be damaged, since the fault duration would be reduced. The installation of additional Petersen coils would reduce the overvoltages for faults at any location. Overvoltages are discussed in more detail in a later section.

Lightning-Arrester Rating

1. On a system having the neutral effectively grounded, these ratings can generally be approximately 80 per cent of the maximum line-to-line voltage.

2. On an isolated-neutral system, these ratings must be at least equal to line-to-line voltage.

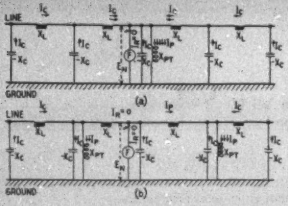

Figure 1. Zero-sequence network, showing effect of one Petersen coil (a) and two Petersen coils (b) on the distribution of fault current due to a single line-to-ground fault

X_L = Line series reactance
X_C = Line shunt capacitive reactance to ground
X_{PT} = Reactance of Petersen coil with associated transformer (per-phase value of transformer reactance X_{TR} plus three times the actual Petersen-coil reactance X_P)
X_{TR} = Reactance of transformer used with Petersen coil
X_P = Actual Petersen-coil reactance (1/3 the per-phase value)
I_C = Charging current to ground
I_P = Petersen-coil current
I_R = Residual current
F = Single line-to-ground fault
E_N = Volts, line to neutral

These zero-sequence quantities are the usual values, per phase, based on three conductors in parallel, except the Petersen-coil reactance, which is actual reactance. Actual currents at point of fault and in Petersen coils are three times the zero-sequence current

3. On a Petersen-coil system, these ratings cannot be appreciably lower than for an isolated-neutral system, provided only one Petersen coil is installed. With additional Petersen coils, it may be possible to reduce these ratings somewhat.

Effect on Communication Facilities

1. With a grounded-neutral system, the fundamental-frequency induced voltage resulting from single line-to-ground faults may be excessive.

2. On isolated-neutral systems, while the fundamental-frequency induction on all but very extensive systems is usually less than for grounded-neutral systems, noise-frequency induction may be severe due to the possibility of long-duration ground faults.

3. An installation of Petersen coils usually reduces the effects on communication facilities considerably, as the magnitudes of the current carried over the transmission lines during faults would in general be smaller. For certain fault and exposure locations, the residual current in an exposure may be almost zero. The number of locations at which the residual current would be small increases as the number of Petersen-coil installations on the system is increased. This is especially important upon the occurrence of a permanent fault, such as a conductor lying on the ground. The effect of additional coils in reducing line currents is shown in figure 1.

Shock to the System

1. With a grounded-neutral system, a ground fault may result in a great shock due to the heavy current.

2. With an isolated-neutral system, a ground fault may result in a large voltage shock.

3. A properly designed Petersen-coil system results in very little shock to the system upon the occurrence of a ground fault.

The principal advantages of Petersen coils, therefore, are seen to be the clearing of most ground faults without the operation of circuit breakers or interruption to service, the reduction in damage at the point of fault and in effects on communication resulting from reduced fault currents, the reduced overvoltages as compared to an isolated-neutral system, and the reduced shock to the system caused by ground faults.

In considering the installation of Petersen coils, the following limitations of the coils should be kept firmly in mind:

1. They do not compensate for the in-phase component.

2. They do not entirely prevent system overvoltages to ground from exceeding normal phase-to-phase voltages, but only limit their extremes in magnitude and restrict their duration.

3. They require that all apparatus and equipment connected between line and ground be capable of sustaining overvoltages.

4. They have no effect on phase-to-phase faults as such.

5. They do not clear permanent ground faults, but help to mitigate their effect.

Each of the above factors must definitely be taken into account when considering Petersen coils in order to determine their efficacy.

Zero-Sequence Capacitive Reactance and Residual Charging Current to Ground

The first step in any calculations for applying Petersen coils is the determination of the zero-sequence capacitive reactance of a short line section with one conductor grounded, neglecting the effect of line series reactance. Methods of calculating this value on a per-phase-per-mile basis are given in several works.[3,6]

If the residual charging current to ground with one conductor grounded is first obtained by test or otherwise, it may be expressed on a per-mile basis. For later use in combining with other network reactances, the zero-sequence capacitive reactance to ground in ohms per phase should be obtained by dividing the volts to neutral by 1/3 the charging current to ground in amperes. This charging current is the same as the charging current to ground from all three conductors connected in parallel and energized at line-to-neutral voltage. Roughly, its value for single-circuit lines of moderate or high voltage is 1.5 to 1.7 times the per-phase value of normal three-phase balanced charging current of the line. This value does not include any in-phase component or the effect of line series reactance.

Where double-circuit lines are involved, the value of residual charging current per mile per circuit must be reduced since the residual charging current to ground of one mile of double circuit line is considerably less than twice the value for one mile of single circuit line of equal spacing.

The capacitive reactance to ground is influenced by a number of factors such as the effect of: the supporting poles, substation structures, and trees and shrubbery along the right of way, and variation in sag, etc. Although the value can be calculated quite accurately, as shown in part II, it is usually advisable to check these calculations by test for any particular system if there is any question about the accuracy of the fundamental data.

A few transpositions may be necessary in the transmission lines to prevent a residual voltage of considerable proportions being maintained on the system during normal conditions, with a consequent flow of current through the Petersen coil.

In-Phase Component of Fault Current

Petersen coils do not balance out the in-phase component of current in the arc caused by losses, such as corona loss, leakage over insulators, unbalanced copper losses, and Petersen coil losses, nor do they balance out the harmonic currents in the arc. The in-phase component must be carefully checked to make sure that it will not be large enough to maintain the arc readily and prevent extinction by the Petersen coils. Fortunately, the arc will be self-extinguishing with a larger magnitude of in-phase component than of quadrature component of current, as the current and voltage will

3. For all numbered references, see list at end of paper.

both go through zero at the same instant.

The in-phase component varies considerably with weather conditions and is difficult to calculate accurately. Unless preliminary consideration shows that the value is small, it is desirable that tests be made on a power system to determine the magnitude of the in-phase component before Petersen coils are applied. It is also important to keep in mind that the magnitude of this component is generally reduced as the number of Petersen coils on the system is increased, as the current through the lines and the voltage distortion over the system would be reduced. An example of the magnitude of this component is shown in part II.

Methods of compensating for the in-phase component have been developed, but the complications involved tend to make their use undesirable.

System Voltages and Effect on Currents

On an isolated-neutral system the voltages at the point of fault are displaced so that ground is at one corner of the voltage triangle, the delta (line-to line) voltages remaining approximately unchanged in magnitude. As locations distant from the point of fault are considered, the voltage triangle shifts further away from ground due to the effect of charging and in-phase components of current being drawn over the series impedance of the line. The result is that voltage appears on the faulted conductor (voltage $Z'G$ of figure 2*c*), and the voltage of the conductor ahead of the faulted conductor in time sequence has a voltage to ground greater than the normal line-to-line value (voltage $Y'G$). If the transmission system is at all extensive, the effect of the series impedance is much more important than usually thought and may easily impress a voltage between an unfaulted phase and ground of 120 to 150 per cent of normal line-to-line voltage. In extreme cases, a condition of resonance between capacitive reactance to ground and series reactance of the line may be obtained with one conductor grounded.

The effect of series reactance is especially important if a long section of small-conductor line connects two capacitance centers of the system.

The reactance of a Petersen coil is not of a sufficiently low value to hold the neutral of the associated transformer at ground potential during a ground fault, and the system voltages are displaced to a condition approximating that on an isolated neutral system. If there is only one Petersen coil on the system and the fault is near the coil, voltage and current conditions on the lines will be approximately the same as on an isolated-neutral system. This results in an increase in the total charging current and, therefore, increases the capacity required in a Petersen coil. These effects can be reduced, however, by the installation of additional coils, as the charging current for any section of the system can then be balanced out by a nearby coil and large currents will not have to be drawn over the line impedance.

On some systems, particularly those with small conductors and high voltages or at high altitudes, the increase in corona current due to the increase in voltage at points distant from the ground fault may be an important factor in preventing the successful operation of the coil.

Number of Coils Required

As the fault location is moved in from the ends of the system toward a Petersen coil, the lagging current through the Petersen coil will increase appreciably; also the charging current of the system. If the Petersen coils are in tune for a fault at any one location on the system, they will be in tune for a fault at any other location, provided the system itself does not change by having lines switched on or off. This applies regardless of whether there is only one Petersen coil or several. As regards the number of grounding points, this is different than the application of grounding banks on grounded neutral systems, since then it may be necessary to place the banks close enough together to give adequate current for relays, and more than one bank is almost always required for directional selectivity.

If the scheme is used of short-circuiting the coils in case the fault should continue for an appreciable length of time, and tripping the faulted line out by ground relays, then at least two Petersen coils are frequently desirable.

Two or more Petersen coils may also be desirable for other reasons. In case the transmission system is likely to be split so that sections would otherwise be without a Petersen coil, it may be desirable to install additional coils in these sections. It will then usually be possible to set the coils on a reactance tap such that the coils will remain approximately in tune even though the system is split apart, regardless of relative size of the sections. This also avoids the possibility of considerable over-compensation from a coil in case it becomes separated from a large part of the system.

As previously mentioned, the voltage distortion in a transmission system, magnitude of total charging current, and total capacity required in Petersen coils will be somewhat reduced by the installation of additional coils and best results will be secured if they are located near the capacitance centers of the system.

System Neutral Connection

The transformer bank to which the Petersen coil is connected may be either a transformer which is used for the transmission of power or it may be a special transformer for the Petersen coil. The types of transformer connections which can be used are the same as those for system grounding; namely, wye-delta, zigzag auto, wye-wye-delta (for use also as power transformers in parallel with delta-delta connected banks), or transformers connected with one winding zigzag and the other winding delta (for operation in parallel with delta-delta transformers).

One type, known as a "Bauch" or "Bauch-Quenching" transformer, combines the grounding transformer and the adjustable reactor. The grounding transformer is a wye-delta unit. The wye winding is connected to the line and

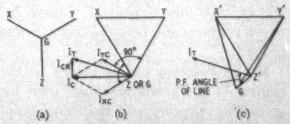

Figure 2. Effect of ground fault and charging current on system voltages, showing: (a) unfaulted line; (b) faulted line, phase Z, at point of fault; and (c) faulted line at point distant from fault

XG, YG, ZG	= Line-to-ground voltages
XY, YZ, ZX	= Line-to-line voltages
I_{YC}, I_{XC}	= Charging current to ground (quadrature component) of unfaulted phases
I_{CR}	= In-phase component of current to ground of unfaulted phases
I_T	= Total current to ground of unfaulted phases

has its neutral solidly grounded. The reactor is connected across an opened corner of the delta winding and is tapped so as to be adjustable for proper tuning.

A number of factors enter into the kilovolt-ampere rating of the transformer

used with a Petersen coil. If the transformer is a special one used for the coil only, it may be of the same kilovolt-ampere and time rating as the coil. The time rating should generally be at least ten minutes and possibly even continuous, depending upon the method used for isolating permanently grounded line sections. If the coil is to be short-circuited for relaying when a permanent fault occurs, the transformer should have adequate capacity to meet the grounding requirements of the transmission system. This will require at least four or five times the amperes capacity required for Petersen coil operation but the time rating will be on a much shorter basis, usually not over sixty seconds. The higher capacity but shorter time may therefore result in a transformer having a physical size not greatly different than the lower-capacity longer-time transformer required for Petersen-coil operation only without short-circuiting.

Accessory Equipment

Some means of protecting the coil from overload is necessary in case a line conductor becomes permanently grounded. The circuit to the coil can be opened, or the coil can be short-circuited to give ground relaying. Either circuit breakers or motor-operated air-break switches can be used for these purposes, and must be capable of withstanding at least line-to-neutral voltage between contacts and between contacts and ground.

If the Petersen coil is placed in the neutral of a transformer bank used for grounding purposes only, switching equipment in series with the coil can be omitted, but some means should be provided for disconnecting the transformer from the line or bus. At the lower voltages, fuses may be satisfactory, although there is an inherent difficulty in distinguishing between line faults (for which the fuses should not operate), and transformer failures (for which the fuses should operate). Use of a circuit breaker is highly desirable, but it is possible simply to use air-break switches to disconnect the transformer manually when necessary, and to treat transformer faults the same as bus faults.

The Petersen coil ordinarily must be removed from service by one of the above means when tap changing is necessary. An alarm relay and graphic ammeter connected to a current transformer in the permanently grounded lead from the coil are desirable, in addition to relays for operating the switches to short circuit or open the Petersen coil for permanent faults. The current transformer can have a comparatively low voltage rating.

Preliminary Determination of Coil Impedance and Current Rating

The fundamental factors which must be considered to determine the approximate impedance and current rating of Petersen coils are given in the following outline. The detailed methods of calculation are shown in the example of part II.

If the transmission system is not extensive the coil or coils will have a large impedance in comparison with the series impedance of the transmission lines. In this case neither the Petersen-coil current nor the charging current will vary much with faults at different locations and the effect of line impedance can be neglected. With an extensive transmission system, the Petersen-coil impedance will become smaller and the series line impedance larger. The latter then becomes an important factor.

The first step in calculating the coil ratings is to determine the value of zero-sequence capacitive reactance to ground for a short section of transmission line. The next step will depend upon the size of the transmission system to which the coils are to be applied.

Coil Rating—
Short Transmission Systems

For the most simple case, with one coil and a short transmission system, all the capacitive reactance can be considered as lumped at the Petersen-coil location and the series reactance of the line need not be considered. Neglecting positive- and negative-sequence values for the preliminary calculations the inductive reactance of the coil *with* its associated transformer must equal the capacitive reactance of the transmission system to ground.

From this value determined for the reactance of the Petersen coil with its associated transformer, the reactance of the transformer must be subtracted, and the difference divided by three to determine the actual reactance of the Petersen coil itself. This division by three is necessary since per-phase values are ordinarily used and the Petersen coil must carry the zero-phase-sequence current from all three conductors. The current rating is approximately equal to the total residual charging current to ground (determined as previously described) and the voltage rating is equal to the actual Petersen coil ohms multiplied by this current. This voltage is slightly less than the normal line-to-neutral voltage of the system.

In the zero-phase-sequence network, the three phases of the transformer and line are connected in parallel and line-to-neutral voltage applied between them and ground. The per-phase values are, therefore, different than the total values by the factor of three. It would be possible in calculations of an approximate nature to use the total zero-sequence values, which with phase-to-neutral voltage would give the actual coil reactance directly without the necessity of dividing by three. The use of per-phase reactances on the other hand in conjunction with line-to-neutral volts gives the zero-sequence component of the fault current and this must be multiplied by three to get the total fault current. It is much better to use the per-phase values, as the refinement of considering positive- and negative-sequence reactances can easily be added since they are always per phase.

Coil Rating—
Extensive Transmission Systems

If line series reactance must be taken into account, the most simple case is a single transmission line with a Petersen coil at one end. If the line is not over about 100 miles in length, the capacitance can be considered lumped at the ends or in the middle (π or T line). If π lines

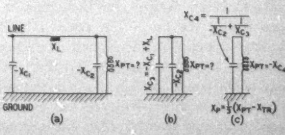

Figure 3. Method of combining line series and shunt capacitive reactances to determine Petersen-coil reactance. The network is reduced to that indicated at (c) and the actual Petersen-coil reactance is then determined by the equation shown

X_{C1} and X_{C2} are the zero-sequence capacitive reactances to ground for the two ends of the line, which are combined as indicated to determine X_{C3} and X_{C4}. See figure 1 for explanation of other symbols

are used, half the capacitance is lumped at each end and expressed as a capacitive reactance. The capacitive reactance at the far end is then combined with the line series reactance (only zero-phase-sequence values being used for the approximate solution) by subtracting one from the other to obtain an equivalent reactance at the Petersen-coil location.

(See transformation a to b of figure 3.) This value must then be combined with the capacitive reactance of the line assumed at the Petersen-coil end (reactances in parallel) to give the equivalent total capacitive reactance at the coil location. (See transformation b to c, figure 3.) The rating of the coil is then obtained in the same manner as in the most simple case where no line series reactance was considered, and is shown in the equation below part c of the figure.

In case of a more extensive transmission system, the line series reactances and lumped shunt capacitive reactances to ground of several short line sections (not over about 100 miles in length) are combined step by step in the same manner to obtain an equivalent total capacitive reactance for the system, referred to the Petersen-coil location or locations.

Positive- and negative-sequence values can be included in the usual manner, although if there are transformers and generators supplying power at different points of the system, the positive- and negative-sequence values usually will be sufficiently low in comparison with the zero-sequence values that they need not be considered in preliminary calculations.

Other Factors in Rating

To provide for proper tuning when a section of the transmission system has been switched off, additional reactance is required in the coil and may be of a lower current rating. This additional reactance must be sufficient to give tuning for the minimum transmission system expected, or down to an arc current value sufficiently low that the arc will be self-extinguishing even though the charging current is not entirely balanced out by the coil current.

The questions of tap steps, tap changers and operating mechanisms, coil insulation and protection against surge voltages, and other design factors have been covered in a recent Institute paper by Mr. E. M. Hunter.[1]

Part II—System Analysis and Computations—By F. Von Voigtlander

Introduction

IN PART I of this paper entitled "Operating Features and Basic Calculations," by W. C. Champe, a discussion of the application of Petersen coils to power systems for the purpose of improving service through the prevention of outages and interruptions due to ground faults is presented. It is the purpose of part II of this paper to present in some detail the method of computation and analysis for the prediction of the behavior of a power system under the condition of single line-to-ground fault with the neutral of the system grounded through a resonant neutral grounding reactor or Petersen coil.

For purposes of discussion, a representative type of power system to which a Petersen coil could be successfully applied is set up and the solution of the required range of reactance and rating of the coil together with resultant ground-fault currents in various branches of the system is presented for two different conditions of system operation. On the basis of the most severe single line-to-ground fault conditions, with the coil applied to the system, the voltages appearing between the phase conductors and ground at the fault and at a station remote from the fault are calculated. To demonstrate the effectiveness of the Petersen coil, results of computations are also given for the fault currents and voltages which the system would experience with the neutral totally isolated. The relative accuracy of the computations and permissible approximations are discussed and an outline of field tests to corroborate design computations and to later check the performance of the Petersen coil after installation is presented.

In the consideration of the application of Petersen coils to a power system, it is assumed here that operating records on the system under consideration have shown that a sufficiently large number of service interruptions due to transitory ground faults have been experienced to warrant the expense of the application of Petersen coils to reduce troubles from this cause. If, for example, 75 per cent of all outages were due to transitory ground faults, a Petersen-coil installation which was, say, only 50 per cent effective, would still provide considerable relief. However, if only 25 per cent of all outages were due to transitory ground faults, the coil installation would have to be much more effective to be justified.

It is of importance, therefore, to carefully analyze the performance of the power system to determine in advance the range of ground fault currents, the relative importance of the in-phase components, and the range of dynamic voltages to ground that may reasonably be expected in operation. These data will serve not only as a basis for the design of the coils, but also to evaluate the probable effectiveness of their installation.

Analysis of a Simple Radial System of Moderate Capacity and Voltage

A general type of isolated-neutral power system has been taken for consideration, consisting of a simple radial network of moderate capacity and voltage, with lines of ordinary wood-pole construction without ground wires and with the conductors sufficiently transposed to keep the normal residual voltage within reasonable limits. This system has been selected as an example of a type to which a Petersen coil can be applied with reasonable assurance of satisfactory results with the possible exception of complete reduction of system overvoltages.

This system shown in figure 1 consists of 33-kv single-circuit, three-phase, 60-cycle lines using wood-pole construction of uniform configuration with number 1/0 copper conductors throughout. The system is supplied by three 1,500-kva generators through a 4,500-kva step-up transformer bank supplying a number of delta-connected transformers along 210 miles of line. All transformers are assumed to be of the two-winding type, delta-delta connected, except at the generating station, which is delta on the generator side but wye on the 33-kv side.

Since the conductors are of reasonable size and the voltage is moderate, corona is no factor and can be eliminated from consideration. Resistance of the conductors could well enough be neglected except that the in-phase component of fault current and line-to-ground voltages are to be computed. It would be expected, however, that the in-phase components of ground-fault current would be too small to sustain the ground-fault arc. The Petersen coil, therefore, would be quite effective in arc extinction if located at any point on this system, but to obtain the maximum effectiveness, particularly in the reduction of system line-to-ground overvoltages for ground faults at all locations, the coil should be located at the capacitance center of the system, which in this case would be at station B. However, practical considerations would probably dictate the location of the coil at the generating station A, where a neutral connection of adequate capacity is already available, though in this location the coil would have but limited effect in the reduction of system overvoltages for ground faults at or near the generating station.

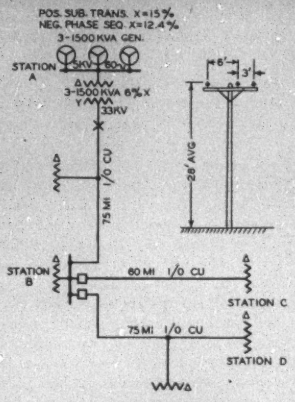

Figure 1. System diagram

Using symmetrical components, the system is divided into its component positive-, negative-, and zero-phase-sequence networks. The impedances of the generators and the transformer bank are known from manufacturer's data which are reduced to ohms on the common voltage base in the normal manner. The electrical characteristics of the transmission lines can be conveniently determined by reference to the tables and curves of Engineering Report No. 37 of the Joint Subcommittee.[3] If test data are not available, earth resistivity may be approximated from the data given in an AIEE paper by R. H. Card.[4] Whenever possible, test data in the vicinity of the system being studied should be used, as earth resistivity may vary quite widely over comparatively small geographical areas and so result in considerable variation in the zero-phase-sequence impedance of the lines. It will be taken here as 50 meter-ohms, a reasonable value for example, in the Great Lakes region. Using the formulas given in tables 2 and 5 and the curves of figures 14, 15, and 16 of Report No. 37, the positive-, negative-, and zero-phase-sequence impedances and admittances of the lines are found as shown in the appendix hereto.

Petersen-Coil Computations

Having set up the component networks, a fault location for worst conditions should be chosen. In this case, the worst location for a ground fault would be at the generating station A, as this would give the greatest residual current in the system, would require the maximum current and minimum impedance in the Petersen coil at A, and would result in maximum voltages to ground on the system, these voltages appearing at station D. It is of interest to note that the behavior of this system under these conditions is essentially that of an isolated-neutral system with the exception that only the in-phase components of current appear in the fault and in the positive- and negative-phase-sequence networks.

The required reactance of the Petersen coil can be found directly from the zero-sequence impedance of the system since under fault conditions, the coil is in parallel with this impedance and it is desired to make the reactance of the coil equal in magnitude to the quadrature component of the system zero-sequence impedance, but of opposite sign. When the value of the coil reactance is established, the resultant currents in the fault and in the coil and the component networks can readily be found. The results of these computations carried out in the appendix hereto are summarized in table I. To demonstrate the effectiveness of the Petersen coil the values obtained for the neutral totally isolated are also shown.

The required range of the Petersen coil is now established as 559 to 812 ohms with a capacity of 34 to 23 amperes, respectively. To provide for system growth, changes in operating conditions, and a reasonable factor of safety, this range of values would be extended somewhat both above and below these limits, as necessitated by local requirements. Since the coil would be required to furnish its rated current only for the duration of the fault, the basis for its time rating would depend largely on local methods for clearing permanent ground faults. Time ratings of either ten minutes, 30 minutes, or continuous are usually specified.

It is of interest to consider whether retuning the Petersen coil is likely to be essential if the branch B-C, which constitutes 28 per cent of the entire system line mileage, is switched off when the coil is tuned for the complete system. With the coil tuned for the complete system, the neutral impedance is $+j1{,}691$ ohms. With the section B-C switched off, the system zero sequence impedance becomes $43-j2{,}450$ ohms. The coil tuned for the complete system would then overcompensate the remaining lines, and a lagging current of $0.39-j10.3$ amperes would appear in the fault. However, even though the coil were not retuned, it would still effect a 57 per cent reduction in fault current and would probably result in fairly effective arc extinguishing for the majority of faults though, of course, satisfactory performance without retuning could be confirmed only by experience.

System Voltages to Ground

For this assumed system the Petersen coil located at the generating station would be very effective in the reduction of ground fault currents to such low values that the arcs would be self-extinguishing. It is therefore of interest to note the dynamic voltages to ground which may be expected to appear on the conductors for single line-to-ground faults on the system. Precise computation of these voltages is beyond the scope of this paper, but reasonably accurate results for most practical cases can be obtained by applying symmetrical components in the usual manner, neglecting the effects of the load and balanced currents, but including circuit resistances.

Solving for the sequence currents and their distribution in the complete system including the Petersen coil, assuming the fault to ground on phase Z at station A as before, the voltage drops in the sequence networks can be computed to the point where the system voltages are desired. The resistive components have been included to demonstrate the difference in voltages to ground of the nonfaulted phases at points remote from the fault, caused by the introduction of the quadrature component of zero-sequence voltage.

The results of these voltage computations as carried out in the appendix hereto are given in table II. The values for

Table I. System Impedances and Fault Currents

	Complete System			Section B-C Switched Off		
	Petersen Coil	Neutral	Isolated	Petersen Coil	Neutral	Isolated
Positive-phase-sequence impedance (ohms)	$+j50.8$		$+j50.8$	$+j50.8$		$+j50.8$
Negative-phase-sequence impedance (ohms)	$+j44.5$		$+j44.5$	$+j44.5$		$+j44.5$
Zero-phase-sequence impedance (ohms)	57,900	$49-j1{,}690$	139,700	139,700	$43-j2{,}450$	
Total equivalent impedance (ohms)	57,900	$49-j1{,}595$	139,700	139,700	$43-j2{,}355$	
Ground fault current (amperes)	0.99	$1.11+j35.8$	0.41	0.41	$0.44+j24.3$	
Petersen-coil current (amperes)	$-j33.8$		$-j23.4$			
Petersen-coil impedance (ohms)	$+j559$		$+j812$			

the neutral totally isolated are also shown for comparison.

Figure 2 shows the vector relations of the system voltages at station A (the location of the fault) and at station D (remote from the fault). The ground fault is on phase Z so that its potential at the fault is reduced to ground potential or zero. The voltages of phases X and Y to ground then become equal to the line-to-line voltages. At station D, 150 miles away, the line-to-line voltage triangle $X'Y'Z'$ is equal to and in phase with the line-to-line voltage triangle XYZ (load and balanced components having been neglected), but $X'Y'Z'$ in this case has been displaced upwardly and to the right. At station A, the line-to-line- and line-to-ground-voltage triangles coincide. At station D the line-to-line-voltage triangle $X'Y'Z'$ is displaced from the line-to-ground voltage triangle $X'Y'G$ due to the rise and line-angle shift of zero-sequence voltage progressing along the line from the fault, so that the magnitudes of the voltages to ground at D no longer equal those at A.

These voltages given in table II are the dynamic voltages to ground sustained by the system for the duration of the fault. Coincident with the fault, tests have shown that voltage transients of the order of 100 kv crest may also be experienced. These voltages, both dynamic and transient, are *not* the result of the operation of the properly engineered modern Petersen coil, but are an attribute of operation with a flexible neutral.

The effect of the Petersen coil in reducing the dynamic voltages which may be experienced during ground faults deserves note, as by means of the coil these voltages may be limited to values safely within the ratings of equipment connected from line-to-ground, which otherwise might be damaged.

The voltages as computed for this system represent the maximum range of dynamic voltages that might be expected because the fault has been placed at the Petersen coil which is at one end of the system so that in this case it has had but limited effect in the reduction of system overvoltages. If a fault location had been chosen elsewhere on the 33-kv system, a greater reduction in these overvoltages would have been effected. The maximum reduction would be experienced for faults at station D, as the lagging reactive current from the Petersen coil would then flow out onto the system to balance the leading capacitance current from the lines and thereby reduce the capacitance current flowing through the system series impedance. If Petersen coils were located, for example, at both stations A and D, dynamic overvoltages to ground on this system would be eliminated, that is, they would be reduced to line-to-line voltages when one phase was grounded.

Accuracy of Computations

In making calculations of power-system fault currents and voltages, the question naturally arises as to what accuracy can reasonably be expected of the results. With the modern methods of computation and with convenient and accurate means available for calculating system impedance characteristics, it will generally be found that the greatest unknowns in the computations are the effects of the various empirical factors upon the system admittance to ground, earth resistivity, and the effects of harmonics.

Tests on a number of systems over quite a range of voltages and configurations have shown the measured values of admittances of short sections of line to be consistently greater than the calculated values. In the author's experience, these differences on well-maintained systems where complete data is available and where corona is no factor, have been found to uniformly approximate ten per cent. Where test data are not available, the calculated values of unit admittance may be increased by this amount with resultant improvement in accuracy. On high-voltage systems where corona is a factor, the calculation of the system admittance is complicated by the necessity for evaluating the capacitance-shunting resistance equivalent of the corona loss, which itself is subject to considerable variation, and by the direct effect of corona on the system capacitance. In making computations in which corona must be considered, it is well to bear in mind also that the corona loss of a system with one conductor grounded is considerably greater than the balanced corona, as has been discussed in various articles on this subject.

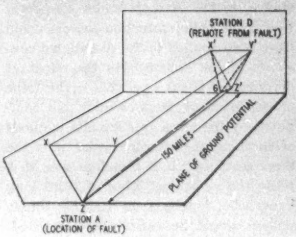

Figure 2. Voltage diagram

If test data are available on the earth resistivity in the territory of the system, the errors due to this factor can be largely eliminated. Where no test data are available, but reasonably accurate estimates can be made, resulting errors in computing zero-sequence impedance may be of the order of ten per cent to 30 per cent. In extreme cases of unsuspected high earth resistivity though, these errors may be greater. However, large errors in zero-sequence impedance will generally not result in proportional errors in fault-current computation because the impedance is usually a smaller factor than the admittance.

All computations involving residual current are subject to errors due to the effects of harmonics in that current. Errors in results due to these harmonics do not usually in practice become as serious as might be expected. However, the possibility of the system being resonant to certain harmonics should not be overlooked, as this can be predicted fairly well from the impedance characteristics of the system.

Tests have shown that when all pertinent factors have been taken into account and reasonably accurate basic data are available, the ground fault currents and voltages can be calculated to within less than ten per cent of their measured values. The in-phase component of system fault currents, however, is subject to considerably greater error, because it is usually a small portion of the total current and is displaced from it by approximately 90 degrees, and because of the difficulty of accurately evaluating leakage and corona.

Permissible Approximations

In any more or less extended analysis of this sort it is, of course, desirable to make such approximations and simplifications as may be made without introducing errors inconsistent with the expected accuracy of the computation. For in-

Table II. Voltages to Ground for Complete System

		Phase X	Phase Y	Phase Z
At station A (fault location)	Petersen coil	33,000	33,000	0
	Neutral isolated	34,500	34,500	0
At station D (remote from fault)	Petersen coil	35,000	35,800	2,780
	Neutral isolated	36,500	37,500	2,880

stance, in the example under consideration, hyperbolic correction factors could have been applied to the distributed constants of the system with the resultant difference of about 1 per cent in the value of system characteristics from that computed by the more approximate methods of lumping the characteristics into the three sections. It is therefore seen that while the additional labor of employing hyperbolic functions in such a simple system would be entirely unwarranted, in an extensive system, it might easily be justified, particularly if the effects of loads and balanced currents were to be considered.

As shown in table I, the magnitude of fault current is but very slightly affected by the resistances in this system and obviously for calculations in which it was not necessary to determine the in-phase component, the resistances could easily be neglected. However for example, if the conductors had a high resistance-to-reactance ratio, or if considerable corona was present, the resistance might easily have become an important factor.

There is always the danger of one attempting to apply the results of approximation in simple cases to complex cases where such approximations may lead to great error. It is, therefore, always advisable to carefully consider the system involved and to observe the relative magnitudes of the various factors which it is proposed to neglect. Approximations, particularly of the rule-of-thumb type, frequently serve to magnify the errors, especially on large and extensive systems, to a point where the computations may be of little value. Considerable experience has shown it advisable to set up the component phase sequence networks completely so that the relative magnitudes of the various factors become apparent before attempting to resort to approximations.

In spite of the various doubtful factors which may come into computations of this sort, the results obtained when based on reasonably accurate system data and on well-considered choice of intangible factors, will amply bear out and justify the efforts put into the work. Although a plus or minus ten per cent error may seem large compared to the accuracy of many other electrical computations, this error becomes small when compared to the error that results from attempting to design a Petersen-coil system without making these detailed calculations.

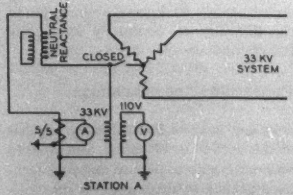

Figure 3. Diagram of connections for tuning neutral reactance

Field Tests to Corroborate Design Computation

Since the installation of a Petersen coil generally involves an appreciable investment, if there is much doubt about the accuracy of the power-system data earth resistivity, etc., field tests to check the results of calculations are easily justified. Before making any tests, however, complete computations should be made in advance, based on the best data obtainable, so that some approximation of the range of expected results can be obtained. By the use of a transformer of the required reactance and rating, a Petersen coil can be simulated if a neutral connection can be made available so that the tests can be made under conditions closely approximating expected operating conditions.

Figure 3 shows a schematic diagram of test connections for tuning a system to resonance with the neutral reactance. Tuning can be accomplished either by varying the reactance in the neutral or by varying the system admittance by switching lines on or off the system as required.

Figure 4 shows schematic diagrams for making the necessary simultaneous surge-recorder, oscillograph and indicating-instrument measurements of neutral voltage displacement, neutral current, fault current, phase angle between fault current and residual voltage, phase-to-phase voltages, phase-to-ground voltages, residual voltages, and transients during the time of the application of solid ground faults and ground fault arcs at the proposed Petersen-coil location (station *A*) and at the remote point of the system (station *D*).

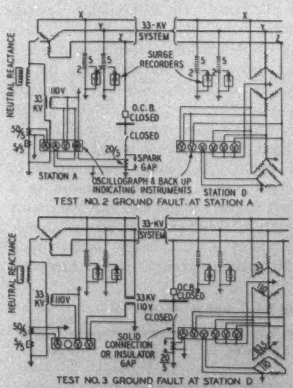

Figure 4. Diagram of system ground-fault test connections

From the results of such tests as outlined, sufficient data can be made available to accurately establish the system's electrical ground-fault characteristics so that the computations can be checked. During the ground-fault tests, simultaneous observations may be made on neighboring communication circuits and factors such as mutual coupling and earth resistivity may be determined.

Field Tests to Check Petersen-Coil Performance

Field tests to check performance of the installation after the Petersen coil has been designed, manufactured, and installed on the system are essential to check the performance of the coil and the system under the various operating conditions likely to be encountered. The setup for these tests would be quite similar to the setup for tests to determine the system's electrical characteristics as outlined in figures 3 and 4. The tests would be carried on in quite a similar manner with the possible addition of tests at various other locations and under perhaps a wider range of operating conditions. If any form of automatic clearing of permanent ground faults has been installed, the functioning of such equipment should also be observed and checked by test.

Tests with the coil tuned for the entire system but with parts of the system switched off should also be made to determine the necessity for precise tuning and to determine the stability of arcs of various current values on the system. In addition, tests can be made of bushing-type current-transformer ratios, effectiveness of relays, effectiveness of lightning arresters, rod gaps, protector tubes, etc., so that a large amount of very useful data can be obtained on the characteristics of the system during abnormal operating conditions.

With the system in reasonably good operating condition all the tests as outlined should be carried on without adversely affecting service on the system during the time of the tests. Since only single-phase ground faults are involved, barring equipment failures such as lightning-arrester failures, bushing flash-

overs, and similar failures, which are commonly experienced on isolated-neutral systems during conditions of single line-to-ground faults, no appreciable effect on the phase-to-phase voltages will ordinarily be noticed.

Conclusions

1. Petersen coils have a definite field of application in improving the performance reliability of a transmission system. However, there are many factors which need to be considered in determining their probable effectiveness in a given installation, including:

(*a*). The relative number of transitory single line-to-ground faults vs. faults from all causes.

(*b*). Magnitude of the in-phase component of fault current.

(*c*). Overvoltages to ground that may occur with faults at different locations.

2. The electrical circuit characteristics of the system during line-to-ground faults must be determined to properly ascertain the coil characteristics. These can be calculated reasonably accurately and substantiated by test.

3. The layout of the system has an important effect on the voltage and current conditions during ground faults. This is especially true if a long section of small conductor line connects two large capacitance centers of the system.

4. Dynamic overvoltages to ground considerably in excess of line-to-line voltages may be experienced during single line-to-ground faults even though the system is equipped with a properly tuned Petersen coil.

5. The ground-fault characteristics of a system both before and after the installation of Petersen coils may be confirmed by relatively simple tests which need not interfere with normal operating conditions. These tests should include measurements of earth resistivity, overvoltages, effectiveness of protective equipment, effect on paralleling communication systems, etc.

Appendix

System Impedances

The positive- and negative-phase-sequence networks of the assumed system are shown in figures 5 and 6 for the fault at station *A*. The portions not shown carry no current. The zero-phase-sequence-line impedances may be determined from table 2 and curves of figures 15 and 16 of Engineering Report No. 37 of the Joint Subcommittee:[3]

$Z_{11} = 0.697 + j1.46$ for 1/0 copper conductors with mean spacing of 5.45 feet and earth resistivity of 50 meter-ohms

$Z_{12} = 0.09 + j0.71$

$Z_0 = Z_{11} + 2Z_{12}$
$= 0.877 + j2.88$ ohms per mile, zero-sequence impedance

The zero-sequence line admittance may be determined from table 5 and figure 14 of Engineering Report No. 37 of the Joint Subcommittee.[3] With line conductors as above at 28 feet average height:

$$C_0 = \frac{0.179}{2\log\frac{4h}{d} + 2\left(2\log\sqrt{\frac{4h^2}{S_{12}^2}+1}\right)}$$

$= 0.00683$ microfarad per mile, zero-sequence capacitance

$= -j388{,}000$ ohms per mile, shunt impedance or $+j2.57 \times 10^{-4}$ mhos per mile, shunt admittance

Zero-sequence network is as shown in figure 7 and reduces to $Z_0 = 49 - j1{,}690$ ohms.

Petersen-Coil Computations

Complete System

Admittance corresponding to above zero-sequence impedance is $Y_0 = (17.3 + j591) \times 10^{-4}$ mho.

Neutral admittance should then $= Y_{PT}$ $= -j591 \times 10^{-4}$ mho or $X_{PT} = +j1{,}691.5$ ohms.

Petersen-coil reactance $(X_P) = \frac{1}{3}(X_{PT} - X_{TR}) = \frac{1}{3}(+j1{,}691.5 - j14.5)$ $= +j559$ ohms.

The zero-sequence impedance of the system including the Petersen coil then reduces to 57,900 ohms and the fault current becomes

$$I_f = \frac{33{,}000\sqrt{3}}{57{,}900 + j50.8 + j44.5}$$

Neglecting the j terms as insignificant,

$I_f = 0.99$ ampere

The current in the coil then is found to be $-j33.8$ amperes and the current in the zero-sequence network becomes $0.33 + j11.27$ amperes.

Section B-C Switched Off

With section *B-C* switched off the zero-sequence network becomes as shown in figure 8 which reduces to

$Z_0 = 43 - j2{,}450$ ohms

or

$Y_0 = (7.16 + j408)\ 10^{-4}$ mho

Neutral admittance should then $= Y_{PT} = -j408 \times 10^{-4}$ mhos or $X_{PT} = +j2{,}450$ ohms. Petersen-coil reactance $(X_P) = \frac{1}{3}(+j2{,}450 - j14.5) = +j812$ ohms.

The zero-sequence impedance of the system including the Petersen coil then reduces to 139,700 ohms and the fault current becomes 0.41 amperes, with a coil current of $-j23.4$ amperes.

With the coil tuned for the complete system but with section *B-C* switched off the zero-sequence impedance becomes $Z_0 = 213.5 + j5{,}460$ ohms, and

$$I_f = \frac{33{,}000\sqrt{3}}{213.5 + j5{,}460 + j50.8 + j44.5}$$

$= 0.39 - j10.3$ amperes

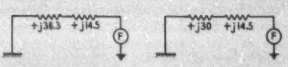

Figure 5. Positive-phase-sequence network

Figure 6. Negative-phase-sequence network

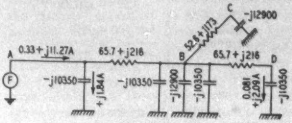

Figure 7. Zero-phase-sequence network for complete system

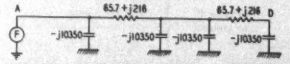

Figure 8. Zero-phase-sequence network with line section B-C switched off

Computation of Voltages

From the coil computations the current in the zero-sequence network is found to be $0.33 + j11.27$ amperes. Current distribution in the network gives $+j1.84$ amperes through the admittance at *A* and $0.081 + j2.09$ amperes through the admittance at *D*.

Voltages at the Fault (Station *A*)

Positive sequence:

$$E_1 = \frac{33{,}000}{\sqrt{3}} - (0.33 \times j50.8)$$
$$= 19{,}050 - j17 \text{ volts}$$

Negative sequence:

$E_2 = 0 - (0.33 \times j44.5) = 0 - j15$ volts

Zero sequence:

$E_0 = 0 - (+j1.84 \times -j10{,}350)$
$= -19{,}050$ volts

From symmetrical components and neglecting the above j voltage terms as insignificant:

$E_x = a^2E_1 + aE_2 + E_0$
$E_y = aE_1 + a^2E_2 + E_0$
$E_z = E_1 + E_2 + E_0$

where $a = -0.5 + j0.866$ and $a^2 = -0.5 - j0.866$

Phase X to Ground	Phase Y to Ground	Phase Z to Ground
$-9{,}525 - j16{,}500$	$-9{,}525 + j16{,}500$	19,050
0	0	0
$-19{,}050$	$-19{,}050$	$-19{,}050$
$-28{,}575 - j16{,}500$	$-28{,}575 + j16{,}500$	0
33,000 volts	33,000 volts	0 volt

Voltages at Station *D* for Fault at *A*

Positive- and negative-sequence voltages at *D* will be the same as at the fault (see above) as these two networks are

considered as carrying no current between *A* and *D* in this case.

Zero-sequence voltage $= 0 - [(0.081 + j2.09) \times -j10{,}350] = -21{,}700 + j840$ volts

Phase *X* to ground	$-9{,}525 - j16{,}500$	
	0	
	$-21{,}700 + j840$	
	$-31{,}225 - j15{,}660$	35,000 volts
Phase *Y* to ground	$-9{,}525 + j16{,}500$	
	0	
	$-21{,}700 + j840$	
	$-31{,}225 + j17{,}340$	35,800 volts
Phase *Z* to ground	19,050	
	0	
	$-21{,}700 + j840$	
	$-2{,}650 + j840$	2,780 volts

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Discussion

H. M. Rankin and **R. E. Neidig**, nonmember (Metropolitan Edison Company, Reading, Pa.): *Part I—Operating Features and Basic Calculations*—by W. C. Champe. The author has covered the ground in a brief but clear and instructive manner. There are, however, a few points on which we wish to comment, as follows:

Lightning Arrester Rating. The author says that with multiple coil installations it may be possible to reduce the rating of lightning arrester below line-to-line voltage. We believe such practice would be questionable, as sectionalizing the system might readily leave any one section isolated with one coil, and the high impedance of the coil would maintain line-to-line voltage to ground on two conductors if the third were grounded.

Advantages of Petersen Coil. Records which we have taken with an automatic oscillograph have never indicated higher voltage to ground than 1.7 times normal line-to-neutral voltage. Our equipment is designed for voltage to ground equal to normal line-to-line voltage.

Transpositions. On existing systems, particularly some of the older ones, it may be difficult and expensive to obtain the proper number of transpositions. We have found it possible in some cases to balance one section of line against another section having a different arrangement of conductors. This, of course, can only be done providing it is possible, when one of these lines is out of service, to cut the residual current to a satisfactory value by detuning the coil still keeping within limits of satisfactory coil operation.

Number of Coils Required. It would seem that the number of coils would depend principally on the possible sectionalized operation of the system rather than on relaying requirements. We are considering the installation of two coils on a system having at present grounding transformers at four locations. The two coils would be installed in the neutrals of two of the grounding transformers and equipped with short-circuiting switches. At the other two locations, we are proposing to simply install neutral grounding switches with suitable automatic control equipment to operate similarly to the short-circuiting switches used with the Petersen coils.

Accessory Equipment. The author states that if the Petersen coil is placed in the neutral of a transformer bank used for grounding purposes only, switching equipment in series with the coil can be omitted. We believe this is somewhat questionable as it might be desirable to use the grounding transformer as such during maintenance work on the coil, in which event means of disconnecting the coil and grounding the neutral would be necessary.

In our installations, we have provided an operation counter as well as alarm relay and graphic ammeter. We have found this advantageous as the chart speed of the ammeter is not great enough to separate the lines drawn by successive operations. For instance, in a recent storm we had five operations of a Petersen coil within a period of 12 seconds. In this particular case, an operator happened to be watching the ammeter and saw the five operations of the needle, which indicated different values of current for each operation although there was only one line registered on the chart. The counter recorded all five operations.

Part II—System Analysis and Computations—by F. Von Voigtlander. Our only comments on Mr. Von Voigtlander's very instructive paper are in the nature of operating results, as follows:

The Metropolitan Edison Company has installed three Petersen coils—one at Reading, Pa., one at Middletown, Pa., on its 66-kv system, and one at Holtwood, Pa., on the system of the Pennsylvania Water & Power Company, with whom they are interconnected. These coils operate on a total of 308 miles of circuit and are tuned for 112, 95, and 101 miles, respectively. They were placed in operation in October 1937, and up to June 16, 1938, the record is briefly as follows: Total faults on 66-kv system—72. Transient faults—64, or 89 per cent of total. Transient faults cleared by Petersen coils—50, which is 78.2 per cent of all transient faults, or 69.5 per cent of all faults on the 66-kv system.

Field Tests. Staged tests were made on this system under various conditions, the worst case being with 25 per cent of the lines for which the coils were tuned disconnected but with no retuning of the coils. These tests were made by establishing an arc to ground across a string of suspension insulators by means of a fuse, and were in all cases successfully cleared within times ranging from one-half cycle to seven cycles. In recent storms, lightning flashovers have also been successfully extinguished with as much as 25 per cent of the line mileage for which the coils were tuned disconnected.

A. W. Gothberg (Public Service Electric and Gas Company, Newark, N. J.): In the paper by W. C. Champe and F. Von Voightlander on "System Analysis for Petersen Coil Application," it is stated that in considering the installation of Petersen coils it should be kept firmly in mind that they have no effect on phase-to-phase faults as such.

This limitation is a severe handicap to an effective installation of a Petersen coil on a system having an appreciable amount of wood-pole transmission. Figures have been published indicating that as many as 75 per cent of the faults on a transmission system are phase-to-phase and as many as 85 per cent of all faults are due to lightning. This clearly indicates that lightning is causing a majority of all faults and on wood-pole lines it is admitted that most of them result in phase-to-phase faults.

A paper has been published in the January 1937 issue of Electrical Engineering entitled "Lightning Protection for Transmission Lines," in which a wood-pole-line design was presented which eliminated or reduced the number of phase-to-phase faults due to lightning. Although this design used lightning-protector tubes on one phase of a three-phase line, it can be made particularly applicable to a system using a Petersen coil by simply substituting a suitable gap for the lightning-protector tubes.

In brief, it would consist of making one phase of each circuit a shielding conductor by locating it so that the remaining phases will be shielded from direct lightning strokes. Lightning currents could be drained from the shielding conductor by means of suitable gaps connected to ground. This would result in a single-phase fault which could be cleared by a Petersen coil. The remaining phases could be isolated from the shielding conductor and the gap ground circuits by insulation sufficient to prevent phase-to-phase faults. On double-circuit lines, gaps could be installed on the two top shielding conductors. It is important that the same phase of each circuit be on the top arm so that in the event of a stroke involving the two top conductors, a phase-to-phase fault does not result. Methods of determining the amount of insulation required on the pole top and the frequency of the gaps along the line can be found in the paper mentioned above.

Limited experience with this type of construction has shown its ability to eliminate phase-to-phase faults.

This proposed design of wood-pole line should make the effectiveness of a Petersen coil on a wood-pole line approach or equal to the effectiveness of a Petersen coil on a steel tower line equipped with ground wires. It would overcome one of the most serious limitations in the application of a Petersen coil to a system having wood-pole transmission.

W. D. Hardaway (Public Service Company of Colorado, Denver): The authors have presented in convenient and useful form, methods for making basic calculations for the application of Petersen coils to transmission systems. They mention the possibility of unsuccessful coil operation due to corona current when applied to high-voltage systems operating with small conductors or at high altitude. In this connection it would be of interest to have stated the maximum values of corona current which are being successfully interrupted by Petersen-coil operation. On the Colorado 100-kv system, fault currents of from 20 to 25 amperes are quenched without difficulty, and North and Eaton report fault currents of from 38 to 50 amperes on the Michigan 140-kv installation (ELEC. ENG., vol. 53, page 67). It appears improbable that these values will be greatly exceeded on other systems.

The authors have called attention to the difficulty in properly relaying an isolated neutral system for single-phase faults to ground. Solidly grounding, with the addition of proper relays, will usually solve this problem. However, the application of a Petersen coil may be materially less expensive than this remedy, and has the further advantage of improving continuity of service. Also it appears that the Petersen coil eliminates the excessive harmonic overvoltages frequently present under arcing ground conditions on isolated-neutral systems.

E. M. Hunter (General Electric Company Schenectady, N. Y.): Continued interest is being shown in the Petersen coil as a service-protective device. At the last winter convention it was reported that there were seventeen coils in the United States, the majority of which have been applied in the last year or so. In the last few months seven more applications have been made, bringing the total to 24. Naturally, some application and operating experience is now available on these protective devices and this experience is the basis of the comments prepared on this paper.

In-Phase Component of Fault Current

In part I of the paper it is stated "The in-phase component must be carefully checked to make sure that it will not be large enough to maintain the arc readily and prevent extinction by the Petersen coil."

I am sure it would be of interest if the authors would give their views on the magnitude of the in-phase component of fault current beyond which it would be undesirable to apply Petersen coils.

Although system analysis and operating experience on existing installations is limited, it indicates that on medium-voltage systems (66 kv and below), the in-phase component of the fault current should not exceed 20 to 25 amperes. This relatively low value of current apparently does not maintain the arc. This is likewise true on high-voltage systems (110 kv and above) unless the system has considerable corona loss. When there is corona and the system is extensive, then the in-phase component of current may be a problem, although in all of the applications made to date, successful arc extinction has been reported with in-phase components of current up to 50 amperes. It appears that the in-phase component of current need only to be considered if there is corona.

System Overvoltages During Ground Faults

In part II of the paper, an analysis is made of the overvoltages on a system (Figure 1, part II) with and without a Petersen coil in the neutral. It shows that with a ground fault on one of the phases at a point in the system adjacent to the station where the Petersen coil is located, the voltage to ground on the two healthy phases increases with distance from the fault point. The magnitude of these voltages is summarized in table II, part II.

Referring to this table, it is seen that the voltages with the Petersen coil increase approximately nine per cent above the system line-to-line voltage at a point 150 miles away from the fault. Since the calculations from which these voltages were derived neglects load current, they undoubtedly represent maximum values. Inductive reactive load current would, in general, have a tendency to reduce these voltages. It should be noted that they do not exceed the maximum permissible line-to-ground voltages recommended for protective equipment on such a system. Also, they are lower than if the neutral were free. These voltages would also be lower if the Petersen coil had been located at station *B* instead of a station *A*. System analysis has shown and operating experience has verified the fact that when overvoltages in remote sections of the system away from the ground fault are likely to be excessive, several coils correctly placed in the system will limit these overvoltages to reasonable values.

It is interesting to note that overvoltages at the point of fault with the system neutral isolated are much higher than if the neutral were grounded through a Petersen coil. For example, on this system of figure 1, part II, the voltages at station *D* for ground faults at station *D* have been calculated for the condition of (1) the system neutral isolated at *A*, (2) the system neutral solidly grounded at *A*, and (3) the system neutral grounded through a Petersen coil at *A*. This study has been made with all three generators in service and also with only one generator in service. The results of this study are summarized in table I.

Table I

Voltage to Ground	Neutral Isolated	Neutral Grounded	Petersen Coil
Three Generators in Service			
Phase *X*	38 kv	24 kv	33 kv
Phase *Y*	41 kv	22 kv	33 kv
Phase *Z*	0	0	0
One Generator in Service			
Phase *X*	41 kv	21 kv	33 kv
Phase *Y*	44 kv	20 kv	33 kv
Phase *Z*	0	0	0

With only one generator in service and the neutral isolated, the voltages are relatively high. This may be explained by the fact that on this system a condition of partial series resonance is obtained. It should be noted that with the Petersen coil in the neutral, the voltages on the two healthy phases do not exceed the system phase-to-phase voltage.

The authors also mentioned high transient overvoltages on the system at the time a ground fault occurs. I would like to have the authors' comment on this further and possibly show how these overvoltages occur and how they may be calculated. Experience indicates that if these overvoltages do occur, they are of a very short time duration, so short in fact that they do not record on a magnetic oscillograph. The magnitude also must well be within the limits of insulation strength of connected apparatus because there is no indication that they do any appreciable damage.

Accuracy of Calculations

The authors state that their system analysis gives results which can be substantiated by tests within a ten per cent error. The experience available to date on Petersen coil applications leads to the conclusion that the methods used by the authors are not necessarily that accurate.

For example, the in-phase component of current for the system analyzed in part II of the paper has been calculated by the authors to be 0.99 ampere. Experience on 11 33-kv applications of Petersen coils leads me to believe that this particular system would have an in-phase component of current between ten and 15 amperes. This would result from leakage on apparatus and also harmonics which appear to have been neglected or omitted from the authors' calculations. This current would vary with the weather, the higher value being noted during stormy periods.

With regard to the charging current in a ground fault which must be compensated by lagging current in the Petersen coil, the experience previously mentioned indicates that this system should have between 42 and 46 amperes instead of the 34 amperes given by the authors for charging current for the 210 miles of line. Possibly this discrepancy may be explained by the fact that in their calculations they have calculated only the zero sequence capacity of the transmission line alone and have made no allowance for the capacitance or apparatus, insulators, bushings, poles, etc. These other effects have a tendency to increase the charging current, making it higher than the current given by the formulas used by the authors.

As suggested by the authors, measurements to substantiate calculations of charging currents are advisable when experience is limited.

W. W. Lewis (General Electric Company, Schenectady, N. Y.): Messrs. Champe and Von Voigtlander give a very useful summary of the conditions that should be considered in the application of Petersen coils. I am especially interested in their discussion of the accuracy of computations on pages 14 and 15 of the preprint and wish to comment briefly on this feature.

If the tests are made carefully and all the conditions are known, and if the calculations are accurately made for the same conditions as existed in the tests, then the results of the tests and calculations should

certainly check. However, usually it is not possible to know all of the conditions of either test or calculation sufficiently well to obtain better than an approximate check. A couple of examples will illustrate this point.

When the Public Service Company of Colorado were considering the application of a Petersen coil on their Shoshone-Denver line, we made some calculations, assuming the average spacing of the conductors to ground as the height at the towers minus two-thirds of the sag. This is probably a fair assumption for level stretches, but as much of this line is in the mountains and spans from hill-to-hill over gulches and canyons, the average height obtained from a profile by planimeter would probably be considerably greater than the height assumed. Allowance was made for the increase in capacitance due to corona and account was taken of the capacitance of the line insulators, apparatus, bushings, disconnecting-switch insulators, and transformer windings. The calculated fault current was 92 amperes capacitance current and 95 amperes including in-phase current due to corona, but neglecting harmonics, for the approximately 187 miles of line. The power company then made some tests in which the neutral was isolated and one conductor grounded. Fault current to ground and voltages to ground were measured with oscillograph, ammeter, and voltmeter. Tests were made at three different points on the system, namely, at the Denver and Shoshone ends and at an intermediate point, Leadville. Reduced to the same voltage basis of 95,000 volts, these tests showed, respectively, fault currents of 123, 101, and 137.5 amperes for the approximately 187 miles of line.

Finally, when the Petersen coil was put into operation, the Petersen-coil currents for ground faults at Leadville and Denver were measured at the tuned setting of the coil ("Test and Operation of Petersen Coil on 100-Kv System of Public Service Company of Colorado," by W. D. Hardaway and W. W. Lewis, ELECTRICAL ENGINEERING, June 1938, pages 295–302). The readings were 98 and 96 amperes, respectively. Thus the calculations checked fairly closely the measured Petersen-coil current but did not check at all well the measured ground fault current.

In another case, a single-circuit 115-kv line with two ground wires was tested. The line was opened up at both ends by disconnecting switches. Low-tension single-phase voltage was placed on the open-circuited line between the three conductors in multiple and ground. Voltage, current, and watts were read. From these readings the zero-sequence capacitance of the line was found to be 0.211 microfarad. The capacitance of the conductors was calculated, assuming an average spacing to ground equal to the height of the conductors at the towers minus two-thirds of the sag. This capacitance, added to that of the line insulators and disconnecting-switch insulators, and assuming no corona, gave a total zero-sequence capacitance of 0.172 microfarad. In this case the tested capacitance was 22 per cent higher than the calculated.

Either Mr. Hunter or I have made calculations for all of the Petersen coils that have been installed in this country and have made ground-fault tests after installation in most cases. From these tests we have worked out the empirical relations shown in figures 1 and 2, for single-circuit lines. These relations can be used as a guide in the selection of Petersen coils.

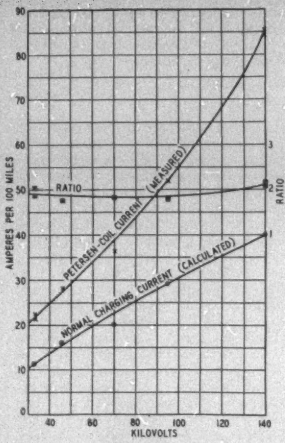

Figure 1

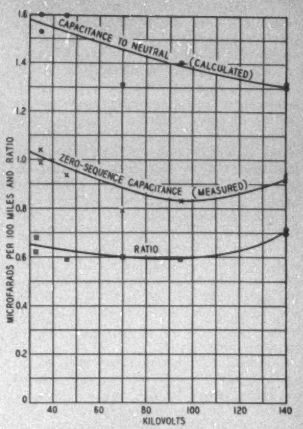

Figure 2

P. A. Jeanne (Bell Telephone Laboratories, Inc., New York, N. Y.): I have been quite interested in the recent activity in the application of Petersen coils in this country, particularly as it has been my privilege, as a member of project committee 2*J* of the joint subcommittee on development and research of the Edison Electric Institute and Bell System, to participate in studies of current-limiting devices, including the tests on the first of the more recent Petersen-coil installations in this country, made in 1931. I think that Mr. Champe and Mr. Von Voigtlander have brought out quite well most of the features requiring consideration in the application of Petersen coils. The comments which I have on the paper are made chiefly from the standpoint of clarifying certain ideas. In the introduction to Mr. Champe's paper (advance copy), the statement is made that with a Petersen-coil system the inductive reactance, most of which will be in the Petersen coil or coils, will be approximately equal to the capacitive reactance of the two unfaulted conductors to ground. I think this statement requires modification because one might assume from it that the proper reactance for the Petersen coil would be one determined from the sum of the direct capacitance to ground of the sound phases, while in fact it is determined from the sum of the direct capacitance to ground of all three phases. I think perhaps the author had in mind the fact that in a Petersen-coil system the charging current of the two sound phases equals the Petersen-coil current, a fact which might readily lead to the statement cited. Perhaps I can make this clear by reference to figure 3. Figure 3(*a*) represents a balanced three-phase power system grounded through a reactor and with a fault on phase *A*. Now if the only voltage in the system were that in phase *A* we could immediately see that for minimum current in the fault the neutral reactance should just equal in magnitude the capacitive reactance of the two sound phases to ground, as that would provide the parallel resonant condition sought. However the presence of the voltages E_b and E_c in the sound phase branches subjects them to higher voltages to ground than that across the reactor and the requirement for resonance is not immediately apparent. Now by a well-known theorem, the current in a particular branch of a network can be determined if an electromotive force equal to that which would exist across an open circuit in that branch is introduced into the branch and the other voltages in the system suppressed. If we apply this idea to the circuit under consideration, as in figure 3(*b*), the current in the fault branch will be the same as it would be with the regular voltages impressed as in figure 3(*a*). It can be seen immediately that, in the circuit of figure 3(*b*), the direct capacitances-to-ground of all three conductors are in parallel with the reactor, so that to secure the parallel resonant condition desired, the reactance of the Petersen coil must be made equal in magnitude to the capacitive reactance of the sum of the direct capacitance to ground of all *three* conductors. The same thing could of course be shown by

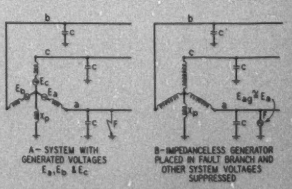
A—SYSTEM WITH GENERATED VOLTAGES E_a, E_b & E_c
B—IMPEDANCELESS GENERATOR PLACED IN FAULT BRANCH AND OTHER SYSTEM VOLTAGES SUPPRESSED

Figure 3. Petersen coil

solving the network of figure 3(a) for a value of reactance which would make the current through the reactor equal to the vector sum of the charging currents of the two sound phases. The authors have used the proper capacitance in their calculations and it is only the statement in the early part of the paper that I feel needs modification.

The second comment I have applies to the discussion of overvoltages under fundamental frequency conditions. While I agree that on an extensive Petersen-coil system the voltage at points remote from the fault may exceed line-to-line voltage, I think it should be made clear that the type of voltage rise the authors discuss is not peculiar to a Petersen-coil system. The effect is the well-known tendency of a long line, energized to ground at the sending end and open at the receiving end, to show a rise in voltage at the open end. If the effect is sufficiently large in the case of a Petersen coil installation to require attention, it would also probably require attention if the same system were grounded at the same point in any other manner. For example, if the system were solidly grounded at one point only, the voltage rise at points remote from the ground might be sufficient to prevent its being treated as a solidly grounded system. In this conection it is interesting to note the tendency of a Petersen coil to establish, at the point of fault, line-to-ground voltages on the two sound phases which are equal to each other and no greater than line-to-line voltage, a condition which other types of neutral impedance may fail to accomplish. Figure 4, prepared for the system assumed in part II of the paper, illustrates the point I wish to make. At the upper left is indicated a neutral resistance grounded system. If, for the sake of convenience, we assume that the neutral remains fixed and allow the point representing the earth to shift with varying voltage drop through the resistor, we can conveniently represent the variation in the line-to-ground voltages of the sound phases. As the neutral resistance is varied, the point representing the earth moves along the circular locus in the diagram in the lower left, and the potentials to the sound phases are measured from the point on the arc corresponding to the value of resistance for which the voltages are desired. This diagram shows quite clearly that with neutral resistance grounding, the line-to-ground voltages of the sound phases are unequal and one of them may considerably exceed the line-to-line voltages, as in the case of phase-C voltage when the neutral resistance is 125 ohms. In the right half of this figure are shown the corresponding diagrams for reactance grounding. It is seen here that as the reactance increases, the locus for the "earth" remains very close to the vector E_A and that the line voltages do not depart very much from balance. In the particular example, the actual departure is even less than shown by the diagram which was distorted somewhat for the sake of clarity. In some types of systems, however, the unbalance may be considerably greater. It is seen that as the value of reactance approaches that required for a Petersen coil, the unbalance tends to decrease, and when it is at the value corresponding to the Petersen coil the line-to-ground voltages are essentially balanced and equal to line-to-line voltage. This is an effect typical of the Petersen coil, and except as propagation effects on long lines may come into play, Petersen coils tend, under fault conditions, to maintain line-to-ground voltage on sound phases substantially equal to line-to-line voltage.

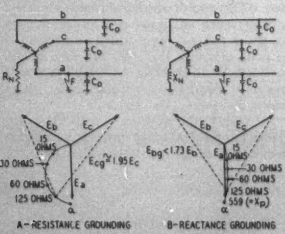

Figure 4. Neutral grounding devices

S. B. Griscom (nonmember; Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors have presented very interesting papers on operating features and computation of Petersen coils. In part I, under "Effect of System Operation," some of the pros and cons concerning the application of coils are given. It seems to me that under this heading a few other factors should be pointed out. One of these for lack of a better term will be called "adaptability to interconnection." Power systems having various types of grounding (solid, resistance, or reactance) may be metallically connected together with but slight changes in the relaying in the vicinity of the tie-in point. With a Petersen-coil-equipped system, however, it is necessary that both systems be equipped with the coils, or else use isolating transformers or their equivalent in making the connection. Thus, all new additions to the system or future interconnections may require the installation of additional equipment. The desirability for Petersen coils should also be considered in relation to the fact that American practice usually provides multiple feeds to important loads to insure continuity not only for transitory but also prolonged faults in case of physical line trouble. The trend toward higher relay and breaker speeds has greatly minimized the shock to the system for faults. A ground fault, unless very close to a full capacity solidly grounded transformer is inherently less severe than a phase-to-phase fault, and very much less severe than a three-phase fault, and the latter must be provided for in any case.

The information given under "Accuracy of Computations," part II, is very interesting. In view of the observed fact that calculated admittances are always lower than test data, I am wondering whether the authors have been able to trace this discrepancy to any commonly neglected factors, such as capacitance of insulator strings, height of vegetation, etc. I understand that in some cases, systems operating Petersen coils have found it necessary to change the compensation due to growth of corn, or the occurrence of a heavy snowfall. In the latter case it would appear more likely that snow or sleet on the conductors would be more effective in changing the zero-sequence capacitance, than a nominal depth of snow on the ground. The writer would like to ask whether any such effect has been noticed on the portion of the Consumers Power 140-kv system that is Petersen-coil equipped.

W. C. Champe and **F. Von Voigtlander:** Mr. A. W. Gothberg has suggested the use of a suitable grounded gap to bridge the insulator of the top conductor of a wood-pole line so that this conductor would act to shield the other two from high induced potentials. The resulting single-phase fault to ground of the combination conductor and shield wire, when discharging a high potential, would be cleared by the Petersen coil. A similar plan has been advanced by the authors and others, and also the possibility of reducing the insulation of the top conductor on steel tower lines without ground wires has been considered on systems equipped with Petersen coils. Though the authors have not had the opportunity of observing such schemes in actual use, it would appear that they would be rather successful in reducing line outages due to lightning and that they would greatly extend the field of usefulness of Petersen coils.

While on highly insulated wood-pole lines, lightning outages may be predominantly phase-to-phase faults, the fact still remains that there are thousands of miles of moderate voltage wood-pole lines in this country on which transitory ground faults are an appreciable proportion of the total faults experienced. This ratio of transitory ground faults to total faults becomes an important criterion for successful Petersen-coil installation. A ratio of transitory ground faults to total faults of as high as 50 per cent is not at all uncommon, particularly on lines of older construction. On such lines Petersen coils have proved eminently effective.

Mr. Griscom has suggested a factor aptly called by him "Adaptability to Interconnection," which is an important consideration in the application of Petersen coils to systems which may be switched onto other systems not so equipped. Where it is necessary to switch a Petersen-coil-equipped system onto such other systems, the switching must be done through transformers having a high zero-sequence impedance, if the effectiveness of the Petersen coils are to be retained, unless the interconnected system is non-grounded and is within the tuning range of the coils.

Mr. Griscom asked regarding the effect of the height of vegetation, increased conductor diameter due to snow or sleet, occurrence of heavy snowfalls, etc., on the tuning of the Consumers Power Company's 140-kv Petersen-coil system. While these factors have an effect on the system admittance to ground, such effects have not been observed to an extent sufficient to warrant retuning of the coils.

Messrs. Griscom, Hunter, and Lewis have commented on the accuracy of computations and on the fact that the observed values of system admittance to ground have always been found to be greater than calculated values. From the tests and calculations which have been made, the effects of height of vegetation, capacitance of insulator

strings, etc., have not been found to be sufficient to account for these differences between observed and calculated admittances.

In the authors' experience, the quadrature components of fault current have been consistently predicted within ten per cent of measured values. In such calculations, the system admittances have been increased ten per cent above the values computed by standard methods, since, as pointed out in the paper, the authors have found the measured values to be consistently ten per cent greater than those calculated on the systems with which they are familiar. In the example in the paper, this ten per cent increase in admittance was not made, as experience on other systems may show a somewhat different relation between measured and calculated admittance. The quadrature component of fault current was calculated in the example as 34 amperes. With the admittance increased ten per cent this current component becomes 38 amperes, which could be expected to be within ten per cent of the measured value on the basis of the authors' experience and about 13 per cent on the basis of Mr. Hunter's experience. The discrepancy between the measured and calculated total ground fault current in the Colorado example cited by Mr. Lewis can probably be ascribed to the magnitude of the in-phase components, since the measured and calculated quadrature components checked quite well. It is hoped that further investigation into the differences between calculated and measured values of line admittances will be made and that the results of such investigations will be made available to members of the Institute. As observed in the paper, the computation of the in-phase components is subject to large error, especially for the smaller values, as the effect of the intangibles on the magnitude of these components then becomes larger than the effect of the system resistances.

Messrs. Hardaway and Hunter have discussed the magnitudes of the in-phase components of fault current on operating Petersen-coil systems. Mr. Hardaway reports in-phase fault current arcs of from 20 to 25 amperes are being cleared without difficulty on the Colorado 100-kv system, and points out that fault currents of from 40 to 50 amperes are being interrupted on the Michigan 140-kv system. The maximum values of in-phase component of ground fault current which can be tolerated for a given system equipped with Petersen coils has not been even approximately established, to the authors' knowledge. Experience has shown that in-phase transitory arcs up to 50 amperes are generally successfully extinguished, though during quiet conditions, such arcs have been known to continue for over 800 cycles. Wind and weather conditions have a very important effect on the behavior of arcs of this sort, and in any test to determine the range of maximum current which can be extinguished wind and weather conditions would have to be considered.

Tests have been made on long and extensive medium-voltage systems where the resistance to reactance ratio was high but corona was no factor, in which sufficiently large in-phase currents were measured to make questionable the successful operation of Petersen coils. On extensive high-voltage systems where corona was present, in-phase components as high as 160 amperes have been calculated. However, in the majority of systems encountered in practice, particularly at voltages under 66 kv, the in-phase components are probably of only secondary importance.

Messrs. Hunter and Jeanne made some very interesting comparisons of system voltages to ground for isolated-neutral, grounded-neutral, and Petersen-coil-equipped systems. In Mr. Hunter's tabulation it is interesting to note for the case of the isolated neutral that as the number of generators on the system is reduced from three to one, the positive- and negative-phase-sequence impedances of the system increase to a point where they are of appreciable magnitude compared to the zero-sequence impedance, resulting in considerably higher system voltages to ground. Incidentally phase-to-phase voltages would also be found to be considerably higher than normal for the assumed ground-fault conditions.

Mr. Hunter asked for the authors' further comment on the high transient overvoltages coincident with line-to-ground faults. The authors believe these transients to be of the nature of switching surges, due largely to the rearrangement of line capacitances to ground incident to the occurrence of the fault. As Mr. Hunter observed, these transients are of too short duration to be accurately recorded on conventional magnetic oscillographs. The authors have not carried out any extensive investigation of these transients, either mathematically or in tests, but have observed what magnitudes may be experienced by the use of surge recorders or klydonographs on systems during ground-fault tests. Such values as have been observed, though of surprising magnitude, have been found to be well within the limits of insulation strength of connected apparatus and equipment. No doubt these transients also are mitigated by the Petersen coils.

Mr. Jeanne observed that the reactance of Petersen coils is determined from the direct capacitance to ground of all three phases of a system, and not from that of only the two unfaulted conductors as might be inferred from the paper. The authors of course agree with this, having the point in mind, as Mr. Jeanne mentioned, that the coil current is equal to the quadrature component of the charging current of the two unfaulted conductors. Mr. Jeanne's discussion and diagrams of these relations and the effect of neutral resistance and reactance on the system voltages to ground are very interesting. They demonstrate the points in question very well, and are worthy of detailed study by everyone interested in this subject.

The empirical relations which Mr. Lewis has shown between the calculated charging current and the measured Petersen-coil current, and the relations between the calculated capacitance to neutral and the zero-sequence capacitance are based on a very wide experience in this field and on a considerable number of tests. They should, therefore, be a useful guide in working out these values for any given power system.

The authors agree with Messrs. Rankin and Neidig regarding the use of lightning arresters rated at less than line-to-line voltage on Petersen-coil systems. However, there appears to be some misinterpretation on the matter of permissible lightning-arrester ratings, as the point intended in the paper was that multiple Petersen coils may permit the use of lightning arresters with a rating lower than those which might be used for a totally isolated system. That is, on a totally isolated neutral system, certain of the lightning arresters might well be required to have ratings considerably in excess of that based on normal line-to-line voltage, whereas on a system equipped with multiple Petersen coils, the rating based on normal line-to-line voltage would probably be adequate. For example, normally on a 33-kv isolated-neutral system, 37-kv lightning arresters would be used. However, if it were a large and extensive system, 43-kv arresters might be required at some stations to interrupt high dynamic overvoltages. If this system were equipped with only one Petersen coil, a number of the 43-kv arresters might still be required, but if it were equipped with multiple Petersen coils, the use of 37-kv arresters might well be feasible throughout.

It is presumed that the maximum recorded voltages mentioned as never having been found to exceed 1.7 times normal line neutral voltage, refer to a system equipped with multiple Petersen coils.

Transpositions are of considerable importance in a Petersen coil application, as their proper use reduces the normal residual voltage of the system and thereby limits the continual current through the coils and restricts neutral displacement during normal system conditions.

The number of coils required on a system would be a function of the possible sectionalized operation of the system. Whether or not all grounding transformers should be equipped with Petersen coils would be a matter for individual engineering judgment on the system involved.

Since there is but little maintenance work to be done in connection with Petersen coils, it would appear difficult to justify any but the simplest means of by-passing the coil and grounding the neutral. Justification for additional equipment would depend largely on local conditions.

The comments of Messrs. Rankin and Neidig on the results of operation with a 66-kv system equipped with three Petersen coils show the effectiveness of this installation. The results which have been obtained with as much as 25 per cent of the system for which the coils were tuned, disconnected without retuning the coils are interesting, particularly as all cases of faults were successfully cleared in comparatively short times.

In closing, the authors extend their appreciation for the many interesting discussions of this paper that were submitted.

The Fundamental Principles of Fluorescence

By GORTON R. FONDA
NONMEMBER AIEE

FLUORESCENCE is a property of many substances. It consists of an emission of light under excitation by radiation whose wave length falls within a critical absorption band. When the emission persists for an appreciable period after the existing radiation has been extinguished, it is known as phosphorescence.

At a low order of brightness fluorescence is encountered in a great number of the organic products of our daily life, such as seeds, plants, woods, eggs, milk products, lubricating oils, print and paper. Their emission exhibits characteristic features that make it possible to determine variations in quality and type.[1] Indeed, fluorescence has even been developed as a tool in microchemical analysis for the detection and estimation of several of the metals as well as of many organic compounds.[2] It appears also among many minerals. Especial interest, however, attaches to artificially prepared products. They include solutions, both liquid and solid, and also solid inorganic substances, such as sulfides, oxides, tungstates, and silicates. Fluorescent solids are generally known as "phosphors."

There are two striking characteristics that one notes in surveying the artificial products. One notices first that fluorescence is frequently associated with the presence of a foreign ingredient at a very low concentration. In inorganic phosphors this foreign ingredient is an appropriate metal at a concentration of one per cent or less. In organic dye solutions, which may be either liquid or solid, it is a dye at a concentration much less than one per cent, with the further limitation that that dye shall be one of a few whose selection depends upon the presence in its molecule of certain derivatives of benzene.

This peculiarity of fluorescence associated with the presence of a specific ingredient at low concentration suggests an analogy with the behavior of a vapor or gas at low pressure within an enclosing tube. In both cases luminescence results by illumination with the light of a critical wave length, and in both cases the luminescence formed decreases in intensity as the concentration of the effective element is raised, whether it be a foreign ingredient in a solid or the pressure of gas in a tube. In the case of a gas the phenomenon is known as "resonance radiation." The illumination exciting it must have a wave length corresponding to an absorption band of the gas. In this way it induces resonance in the atoms or molecules of the gas, exciting them to such an extent through the absorption of energy that an electron is driven out to an outer orbit. The condition for this is that

$$E = h\nu$$

where E is the energy of a quantum of the exciting radiation, and ν is the frequency corresponding to the wave length at which energy can be absorbed to excite the atom to resonance. The luminescence arises from the return of the excited electron to its normal orbit, and this return is accompanied by an emission of energy of the same frequency. Consequently, the luminescence is of the same wave length as that of the exciting radiation.

The condition in a phosphor is more complex because the basic substance, whether solid or liquid, is itself made up of atomic groups at a relatively high concentration, and completely enveloping the scattered, occasional particles of the active ingredient. This characteristic, however, is so far from breaking the analogy with resonance radiation in a gas at very low pressure that it actually serves to strengthen it by acting as basis for an explanation of the one outstanding difference between the two. The explanation is derived from the second observation that becomes apparent to the investigator in his endeavor to pick out the salient features of fluorescence. It is the fact that the fluorescence is not monochromatic, as that of the exciting radiation may be, but extends over a broad band of the spectrum and, in general, is displaced to a position of longer wave length than that of the exciting radiation. This latter characteristic is known as Stokes' Law.

A survey of some characteristic features of resonance radiation will serve to bridge the gap between it and fluorescence, and to demonstrate the basis for the transition to the condition described by Stokes' Law.

The simplest case is that of pure sodium vapor at very low concentration—so low in fact that the time during which an electron stays in an excited state shall be less than the time between collision of the excited atom with some neighboring atom. The luminescence of sodium vapor, such as is exhibited in the sodium lamp, is made up of the *D*-line doublet, 5,890 angstrom units and 5,896 angstrom units. The emission of this doublet, as illustrated in figure 1, is the result of the return of excited electrons from two energy levels lying close together, the $2^2P_{1/2}$ and the $2^2P_{3/2}$, to the lower normal level $1^2S_{1/2}$. When the vapor is sufficiently low in pressure, only one of these lines can be excited as resonance radiation by the absorption of light of corresponding wave length. This is as theory would predict. When, however, the pressure is raised to 0.015 millimeters, corresponding to a temperature of 300 degrees centigrade, or when a fraction of a millimeter of hydrogen is introduced, both lines appear, even though the exciting radiation is limited to one line. This is due to a collision of some of the excited atoms with neighboring atoms. Such a shock leads to an energy transfer sufficient to throw the excited electron into the closely adjacent energy level, for the energy difference between the two states yielding the doublet corresponds to only 0.01 volt. The result illustrates for a system as simple as sodium vapor how sensitive the character of its radiation is to the influence exerted by neighboring atoms upon one another, even while at a relatively low concentration.

The condition becomes more complex for a vapor such as iodine which is in the molecular rather than the atomic state. In iodine vapor the two atoms constituting the diatomic molecule are free to vibrate back and forth with respect to one another, making various vibrational energy states possible. Furthermore, the

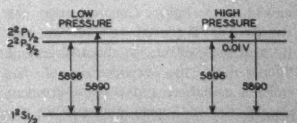

Figure 1. Energy-level diagram for resonance radiation of sodium vapor

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1. For all numbered references, see list at end of paper.

Figure 2. Resonance spectrum of iodine vapor, as affected by presence of helium (From R. W. Wood and J. Franck, Verh. d. D. Phys. Ges., 13, 85, 1911)

A—No helium
B—Two millimeters of helium
C—Ten millimeters of helium

molecule can rotate about the axis uniting its two atoms, thus giving rise also to various states of rotational energy. Consequently, there are not only the usual number of electronic energy levels, but each one of these levels is subdivided into additional ones corresponding to the possible vibrational energy states, and each one of these is subdivided again into a series of rotational energy levels. For iodine vapor the case is rendered so complex by these features that its pure resonance spectrum no longer consists of a single line but of a succession of doublets.

A more significant feature, however, is shown by an increase in pressure sufficient to lead to collision of excited iodine molecules with neighboring molecules. The resulting energy interchange is such as to shift the excited electrons to adjacent vibrational and rotational states. Consequently, when the electrons return to their normal orbit, it will no longer be by a succession of definite, specific jumps, leading to an emission of clear-cut doublets, but rather by jumps of variable magnitude, the energy of each of which is determined by that of the abnormal excited state attained in the collision. These states are so close together that the resulting emission can no longer be resolved into lines, but appears as continuous radiation arranged as bands at the location of the expected doublet. There is still another effect associated with high pressure. As the result of collision, the excited electron itself loses energy on its return to the normal orbit, leaving a smaller amount available for emission as light. Consequently, the emission is displaced toward the red. Both of these effects, so characteristic of fluorescence, the broadening of the emitted radiation and its displacement toward the red, were produced in the resonance spectrum of iodine vapor by the introduction of helium, as well as by increases in the vapor pressure of the iodine,[3] as shown in the photographs of figure 2.

These observations on resonance radiation illustrate how complications arise even in the gaseous state, as one passes from a monatomic to a diatomic vapor and from very low pressures to pressures of a few millimeters. It can, therefore, be readily comprehended that, as the concentration of atoms and molecules is still further increased to such a point that their condition becomes that of a liquid or a solid, the mutual interplay of forces between them will become much more intricate and involved, and their effect still more pronounced on the character of the emitted light. The theoretical development in recent years has, in fact, shown that the energy states in a solid can no longer be represented by a few lines of discrete energy values, as in a monatomic gas at low pressure, or even by large groups of lines corresponding to the vibrational and rotational states of a diatomic gas. The interplay of forces between atoms as contiguous as in a solid is so manifold that each group of electronic levels becomes packed with many lines and develops into what is virtually a continuous band of energy. This condition is illustrated in figure 3 by contrast with that for a vapor already brought out in figure 1. A detailed discussion of the situation is given in a recent review by Seitz and Johnson.[4]

In figure 3 two such bands are shown. The lower one represents the outermost energy state under normal, unexcited conditions. The upper is referred to as a "normally empty band." It represents the energy state into which an electron would be driven if excitation could occur. In solids which are insulators at room temperature, the bands are so far apart in energy content that the available processes for excitation are insufficient to raise an electron from the filled band to the upper unfilled one. The case becomes different, however, if in some way a localized state may be inserted between the two bands. Such a condition is produced for instance when a small amount of an impurity is dissolved in the crystal. Some of the energy states of this impurity will of course fall within the normal banded levels of the solid, but under appropriate choice the uppermost filled level of the impurity will appear as a discrete, localized state, lying above the filled band of the crystal, as shown in figure 3. Its position with reference to the upper unfilled band of the solid, can be assumed to be such as to allow of excitation under radiation of appropriate wave length, causing an electron to make the jump from this localized level into the unfilled band. The consequence will be that an emission of fluorescence will occur, associated purely with this impurity atom. The excited electron will descend by a series of thermal interchanges to the bottom of the unfilled band. Consequently, the energy emitted by its return from this point to its normal state will be lower than the energy of excitation, and the resulting fluorescence will be displaced toward longer wave lengths.

Complicating features due to the proximity of neighboring atoms of the solid have the effect of broadening the emission into a band. The cause of this effect, as well as the extention to longer wave length, can be more clearly discerned by consideration of the Franck-Condon Principle.

In the diagram of figure 4 the abscissae denote the distance between an atom of the foreign metal and, for simplicity's sake, one of its neighbors. Due to thermal vibrations and under the alternate forces of attraction and repulsion, the distance between the atoms will vary periodically so that the potential energy may be represented by the ordinates of the two curves, N for the normal condition of the metal atom, and E for its excited state. Consider that the vibra-

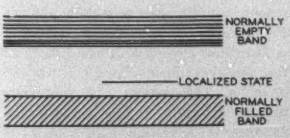

Figure 3. Energy bands for a solid

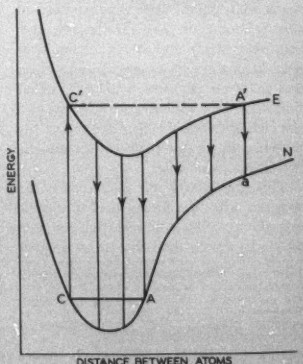

Figure 4. Excitation and emission of a phosphor according to Franck-Condon Principle

Table I. Fluorescence of Rhodamine B at Various Concentrations in Cellulose Acetate Films

Molar Concentration	Peak Wave Length Fluorescence (Angstrom Units)	Yield of Fluorescence (Per Cent of Radiant Energy)
$4(10)^{-4}$	5,900	5.4
$4(10)^{-3}$	5,930	28.3
$4(10)^{-2}$	6,050	44.0
$4(10)^{-1}$	6,210	4.6
$3(10)^{-1}$	6,250	1.0

tion is such as to lead to maximum oscillations between the points C and A. The Franck-Condon Principle prescribes that the time of excitation is so short as compared with the time of vibration that a transition from the lower to the upper level will take place along a vertical line, such as CC'. While in the excited state vibrations will continue between points of equal potential energy, such as C' and A'. As the duration of the excited state persists over a finite time, the return of the electron to its normal position may be represented as occuring from any position along the curve E between the points C' and A'. It is an inherent feature of the Franck-Condon Principle that the curves E and N shall have the different shapes shown in figure 4 as representative of the difference in the interplay of forces between an atom and its neighbors, depending upon whether the atom is in the normal or excited state. Consequently, the energy emitted by the return of the electron will not be equal to the energy of excitation, represented by the line CC', but will have a succession of lower energy values depending upon the point on curve E from which its return starts and extending as low as the transition $A'a$. Such a process would therefore yield a continuous band of emitted fluorescence

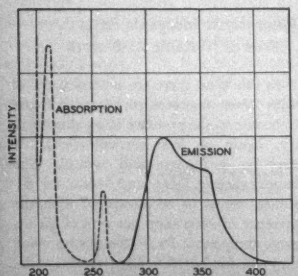

Figure 5. Absorption and emission spectra of potassium bromide activated with 0.003 per cent thallium (From W. von Mayeren, Z. Phys., 61, 321, 1930)

extending to longer wave lengths than that of the exciting monochromatic radiation. This viewpoint has been given quantitative treatment by Seitz[5] for the case of the halide phosphors, developed experimentally by the school of Pohl and Gudden.[6]

It has been convenient to visualize the localized state as one induced by the presence of an impurity atom. It is conceivable, however, that it might be realized in other ways leading to irregularities in the lattice, such as by departures from stoichiometric proportions in the composition of the solid, by a low concentration of an allotropic form of the solid, by the dispersion of the active molecules in a solution, or by their adsorption in dispersed form on a solid. In the discussion that follows of various types of fluorescence, the question is to be kept always in mind—what is the feature that serves as source of fluorescence by introducing a foreign condition into a solid or liquid?

Fluorescent Organic Bodies

There are many organic compounds which exhibit a low fluorescence. Benzene can be taken as an example. As a vapor it can be excited by illumination to yield a purely resonance radiation, also termed fluorescence, consisting of a succession of narrow bands arranged in groups. At closer proximity of its molecules, such as in the solid or liquid condition at zero degrees centigrade or in solution in alcohol, the subsidiary bands of a group agglomerate into a broad band, and these bands become displaced toward longer wave lengths, a trend that becomes still more pronounced as the concentration of a solution is increased. The same observation has been made for all aromatic substances studied, as well as for benzene, namely, that the fluorescence bands are displaced to longer wave lengths as the physical state is changed from a vapor to a liquid or solid solution.[7] The results serve again to illustrate the transition from pure resonance radiation to fluorescence, involving the broadening of bands and the shift in wave length that are consequences of slight increases in concentration. In this type of substance the active group seems to be the molecule itself of the compound, for the fluorescence is virtually extinguished at such high concentrations as are present in a pure liquid. It appears at its best in dilute solutions or in an adsorbed film at high dispersion on cellulose or silk fibers. Variations in the character of this type of fluorescence have been particularly ap-

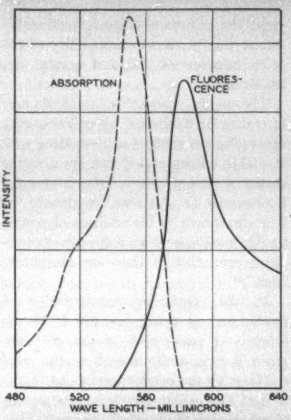

Figure 6. Absorption and fluorescence spectra of rhodamine in alcohol solution (From A. Poristky, Journ. Frankl. Inst., 197, 527, 1924)

plied by Haittinger to a system of organic analysis.[8]

A much higher intensity of fluorescence is exhibited by certain of the organic dyes. It appears only in liquid and solid solutions, and is completely absent in the pure, solid dye. Rhodamine can be taken as a typical example, especially because it was one of the first to be considered for commercial application in fluorescence from a proposal made by Cooper-Hewitt.[8] Its fluorescence can be excited by the ultraviolet, but is more generally excited through radiation with green light lying within the range of its absorption band. The relation between this band and the fluorescence is brought out in figure 6. Each is seen to be roughly the mirror image of the other. The full fluorescent spectrum is excited by any wave length lying within the absorption spectrum.[9] As the concentration of the solution is increased, the band of fluorescence passes through an optimum in intensity and at the same time is displaced toward the red, as brought out in table I for films of rhodamine B in cellulose acetate excited by the mercury green line.[10] The concentrations given apply to the alcoholic solution before evaporation to yield the solid film.

The existence of an optimum intensity of fluorescence at a critical concentration has been found to be a characteristic common to the solutions of all such dyes and to fit the Brunighaus equation[11] $I = kce^{-Bc}$, where I denotes the intensity of fluorescence and c the dye concentration. The decrease in fluorescence be-

yond the optimum value is presumably due to the increase in probability of collision between excited and normal dye molecules.

The energy of an excited molecule may of course be dissipated by collision with any molecules capable of resonating with it. This influence is shown by a wrong choice of solvent, which either lowers the fluorescence or destroys it utterly.[10,12] It is also shown by the addition of certain foreign materials which reduce the fluorescence even though they are chemically inert.[7,12]

At the optimum concentration of rhodamine, as shown in table I, the efficiency of conversion of the mercury green line into fluorescent energy corresponds to the production of one quantum of fluorescent energy by the action of 1.6 quanta of absorbed energy, a conversion that is approaching closely that which would be theoretically attainable.

Fluorescent Inorganic Substances Containing Metallic Activators

Mention has already been made of the alkaline halide phosphors developed by the school of Pohl and Gudden.[6] Fluorescence is absent in the pure halides but appears when a trace of thallium is introduced. The characteristics are presented in the curves of figure 5 for the typical case of potassium bromide. The presence of the thallium gives rise to two new absorption bands. Fluorescence is excited by radiation of any wave length lying within these bands. It seems clear therefore that the fluorescence arises from excitation of the thallium, and the theoretical treatment by Seitz[8] furnishes a quantitative basis for this conclusion.

In the experiments described the amount of thallium in the halides was limited to very small concentrations that would not interfere with the formation of single crystals. The writer has investigated the effect of larger amounts in microcrystals. In general an optimum concentration was found, as is brought out in table II for the case of caesium iodide excited by the mercury line 2,536 angstrom units.

The dependence of fluorescence upon the presence of a foreign metal at low concentration is exhibited in other inorganic materials. For the alkaline earth sulfides and zinc sulfide, extensively investigated by the school of Lenard,[14] these activators include manganese, copper, silver, antimony, lead, and bismuth. The pure sulfides, with the possible exception of zinc sulfide, are devoid of fluorescence in the absence of an activator. The color of their fluorescence varies with the activator used. The fluorescence increases to an optimum value at a critical concentration of the foreign metal and decreases to extinction at higher concentrations, just as for the halides.

Many of the oxides also may be made fluorescent by addition of a foreign metal. Calcium oxide is a typical case. It is activated by manganese, copper, lead, bismuth, and antimony, each yielding a different color. In the extensive investigation by Ewles[15] an optimum concentration was found for each of the last three metals.

The existence of an optimum content of a foreign metal in these diverse types of inorganic compounds is obviously related to the effect of an optimum concentration in solutions of dyes. The fact that the fluorescence reaches a saturated value and then decreases for larger amounts of the metal signifies again that an activated atom can lose its energy when a neighboring atom of the metal approaches it too closely. Unpublished observations by the writer on related effects indicate that this loss is due to the thermal vibrations of the atoms, and that its extent depends upon the amplitude of these vibrations.

Manganese finds very extensive use as an activator. Besides the sulfides and oxides, it has been found also to activate certain sulfates, phosphates, and silicates.[16] In the case of zinc silicate, the writer has found that the fluorescence is displaced toward the red as the concentration of manganese is increased, as brought out in table III.

This result is important in that it demonstrates that the same effect is observable in the fluorescence of inorganic solids as in that of organic solutions and in the resonance radiation of vapors—namely, a shift in the emitted radiation to longer wave lengths that accompanies an increase in concentration of the active ingredient.

A natural query arises as to the condition in which the foreign metal activator is incorporated in the basic substance. Experiments by the writer on X-ray analysis of zinc silicate phosphors have demonstrated that manganese atoms enter into the crystal as integral parts by substitution for occasional zinc atoms. The result is a slight extension in lattice spacing, due to the larger size of the manganese ion, as compared with the zinc.

In a different way Riehl has arrived at the same conclusion for zinc sulfide activated with copper.[17] The crystals of the phosphor were treated with hydrochloric acid so as to dissolve them slowly. As they became smaller, however, the fluorescence characteristic of copper activation continued and persisted almost up to complete solution. This is direct evidence that the copper had penetrated the lattice rather than formed as an adsorbed layer on the surface.

Table II. Fluorescence of Caesium Iodide Activated With Various Percentages of Thallium

Percentages of Thallium by Weight	Relative Fluorescence
0.07	88
0.22	100
0.37	84
1.11	39
8.70	5

Table III. Effect of Manganese Concentration Upon the Color of Fluorescence in Zinc Silicate Phosphors

Percentage of Manganese	Peak in Fluorescence (Angstrom Units)
0.1	5,270
0.4	5,280
0.9	5,290
1.4	5,310
2.3	5,330
4.5	5,350

There are many natural minerals that fluoresce, one of the most notable being a variety of willemite from New Jersey known as Franklinite. So far as these minerals have been investigated, they have been found to contain a foreign metal impurity as source of the fluorescence.[7]

The fluorescent glasses fall in this same classification, for their luminescence under radiation is due to activation by a foreign metal at very low concentration. It may be uranium or even one of the common metals such as manganese.[18]

Fluorescent Inorganic Salts Free of Metallic Activators

In this class there are several types of salts whose fluorescence has been found to be due to the presence of an abnormality, again at low concentrations. It may be a foreign acid radical. The fluorescence in bone and teeth, for instance, seems to be associated with the presence of about two per cent of an organic compound, for it disappears when they are fired at 600 degrees centigrade. Furthermore, it can be produced artificially by the incorporation in calcium phosphate of a small amount of an organic product.[19] Doctor Byler of this laboratory [General Electric Company, Sche-

nectady, N. Y.] has just shown that the fluorescence of calcium phosphate may also be induced by incorporating a critical amount of the acid phosphate in the hydroxy phosphate, and that similar complex salts of other metals can be formed at such critical compositions that fluorescence results.[20]

A related case is that of zinc carbonate which developed fluorescence when it had been fired sufficiently to bring about partial decomposition into the oxide. An optimum fluorescence resulted at a composition of 11 molar per cent zinc oxide combined with 89 molar per cent zinc carbonate.[21]

Still another type of abnormality is represented by the presence in a salt of a small amount of an allotropic modification of that same salt. Doctor Byler developed fluorescence in barium chloride, for instance, by firing it for a short time just above its transition point. Another instance is furnished by the long controversy over the fluorescence of zinc sulfide. The variations in the intensity and color of its fluorescence that have been produced by altering the amount and kind of a foreign metal impurity demonstrate that activation of zinc sulfide by a foreign metal actually exists. However, a low degree of blue fluorescence arises on firing zinc sulfide to which no metallic impurity has consciously been added. There is a suspicion that this arises from the presence of a residual impurity which the chemical purification has not been capable of removing. Schleede, however, has demonstrated that the fluorescence of the purported pure zinc sulfide is at a maximum after a brief firing at 1,000 degrees centigrade, which served to convert a part of it from the cubic to the hexagonal form. He concluded that the fluorescence arose from this intermixture of different crystalline types, for it disappeared under slightly higher firing at temperatures most suitable for the development of fluorescence in the presence of foreign metals.[22] He ascribed the loss in fluorescence of the pure sulfide at such temperatures to its complete conversion to the hexagonal form.

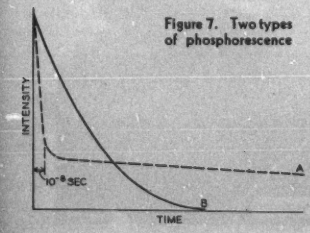

Figure 7. Two types of phosphorescence

There are many metals which can be identified by the fluorescence of their salts, most especially those with certain organic acids. In general, however, this fluorescence is observed as adsorbed films on a suitable base, such as filter paper, or in solution. It would seem to be due, therefore, to a fluorescence of the molecule under the condition of sufficient dispersion to prevent disturbances by collision.[3]

There are, however, other cases in which fluorescence is associated with pure inorganic solids which are not yet known to contain any abnormalities. Such are the salts of the rare earths and of the uranyl radical and also the tungstates and molybdates.[14] It is reasonable to expect that the presence of some abnormality will eventually be found in them also.

Phosphorescence

The light emitted during radiation by the exciting source is known as fluorescence. In many cases the fluorescent substance continues to emit light after the exciting source is extinguished. Such a delayed emission of light is known as phosphorescence. The two are intimately related as manifestation of the same fundamental phenomenon, namely, excitation of an atom. When the excited electron returns directly to its normal orbit, simply fluorescence is observed as the result of what Lenard calls an instantaneous process. When, however, the return of the electron is for any reason delayed, thus giving rise to phosphorescence, then, by way of distinction, Lenard refers to it as the result of a delay process.

Actually fluorescence may persist for an instant, of the order of 10^{-8} second, after the exciting source is extinguished. When no luminescence beyond this period is observed, then one can be assured that the instantaneous process is the only one involved. When phosphorescence is manifested, however, it is clear that both processes are going on simultaneously during direct illumination. Their relative proportions in two different phosphors can be estimated by measuring the rates at which their phosphorescence decays after extinction of the exciting light. If one substance shows a sharp initial decay, less than about 10^{-8} second, such as that represented by the first portion of curve A in figure 7, to be followed by a slow decay which begins at low intensity, then it is clear that the light emitted from it during illumination is produced to a relatively greater extent by the instantaneous process.

The delay process itself is characterized by differences in the speed with which it is carried out. This is manifested by differences in the character of the decay curve. In figure 7, for instance, even though the delay process is predominant in B, yet the speed of its decay is relatively so high that its phosphorescence has fallen to zero at a time when the longer life phosphorescence from A is still observable.

In the case of a sulfide phosphor, there are generally three different types of phosphorescence, each excited by a narrow band of differing spectral distribution The instantaneous process giving rise to fluorescence is excited by a broad band whose spectral distribution includes all of the narrower bands which lead to phosphorescence. The halides offer a contrasting case. In them there are two distinct absorption bands, as brought out in figure 5. Excitation by the one of longer wave length yields only fluorescence, whereas excitation in the shorter band leads to both fluorescence and phosphorescence as well.

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A Memory Attachment for Oscilloscopes

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THE DEVICE described in this paper, called a "memnoscope," is a system for obtaining an oscillogram of random phenomena and events immediately preceding and following its occurrence.

This system was developed and has been used to study arc-back phenomena in mercury-arc rectifiers. Other methods, such as the use of long transmission lines and high-persistence cathode-ray tube screens[2] have been used to obtain oscillograms of random phenomena.

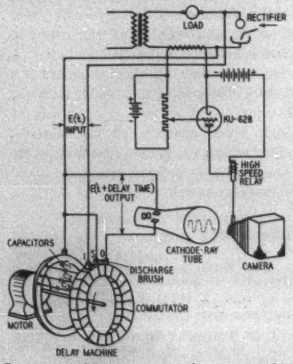

Figure 1. Memnoscope: A system for oscillograms of random events

It is possible to obtain volt-current-time data on one film because the discharge of each condenser element of the memnoscope gives a dot on the oscilloscope record and a knowledge of the commutator speed and number of condensers gives time (see figure 4a). Information on random transmission-line faults can be obtained from normal conditions, through fault time and back to normal.

Description of Complete System

In figure 1 is shown a rectifier which is a source of a random[1] occurrence commonly known as arc-back. If it is desired to obtain an oscillogram of conditions in a rectifier immediately preceding and following the arc-back, a system as shown in figure 1 can be used.

The grid of the thyratron is excited by the random phenomenon and the plate current opens the camera shutter. A picture is obtained of the motion of the spot on the cathode-ray-tube screen. Since the motion of the spot is determined by potentials of the rotating capacitors and if rotation is as shown in the figure, the picture taken will be of events occurring prior to the time the random phenomenon occurred. The heart of the system is the rotating capacitor network designated in figure 1 as "delay machine."

Construction of Delay Machine

To obtain satisfactory oscillograms at 60 cycles, for the conditions investigated, a machine with 147 capacitors was constructed. This machine was built using a standard commutator with 147 bars and 147 0.01-microfarad capacitors mounted around the shaft. One terminal of each capacitor was connected to a commutator segment; the other terminal was connected to a collector ring. The whole assembly was balanced and then mounted in a standard motor frame of suitable size. The size of the completed capacitor unit, which is the machine in the foreground, and the driving motor can be seen from figure 2. The capacitors are of the commercial paper-wax tubular type, $\frac{1}{2}$ inch in diameter and one inch long.

The brushes are mounted close together in order to utilize as many of the total number of capacitors as possible. With rotation as shown in figure 1, I is the input brush, S is the short-circuiting brush, and O is the output brush.

Operation of Machine

Assume the direction of rotation as shown in figure 1 and a voltage $E(t)$ across the input terminals. The resistance and inductance of the input circuit are negligible; then the capacitor, C_1, at the same time it leaves the brush I will be charged to a voltage $E(t_1)$. After a time very nearly $1/rps$ seconds (the delay time) this capacitor, C_1, will be under brush O and the voltage $E(t_1)$ can be recorded. Before C_1 can reach the input brush again, it is discharged by the short circuiting brush S bringing $E(t_1)$ to zero and C_1 is ready for another transfer of charge.

All the capacitors $C_1, C_2, C_3, C_4 \ldots\ldots$ transfer their specific charges once per revolution and a stepped wave $E'(t)$ is obtained at the output end. This wave is $1/rps$ second behind the wave $E(t)$. The number of electrical degrees per step is $\theta = f/rps \times 360/b$. Where f = frequency and b = total number of capacitors in the machine. For 1,800 rpm and a 60-cycle wave $\theta = 4.90$ degrees. This means that there will be 73.5 steps per cycle of a 60-cycle wave.

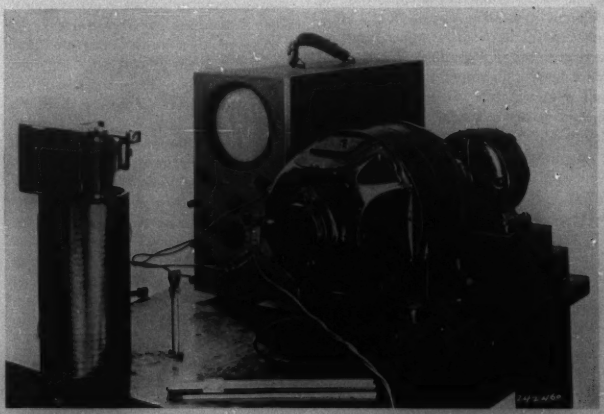

Figure 2. Apparatus as used to obtain pictures. The larger machine contains rotating capacitor network

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2. For all numbered references, see list at end of paper.

The delay time is that of one revolution of the commutator corrected for the total span for the three brushes. In this case it is $t_m = 1/rps \times 142/147 = 0.0322$ second for 1,800 rpm. This time is nearly two cycles of 60-cycle frequency.

Oscillograms, figure 4, have been obtained using a cathode-ray tube, with the output voltage connected directly to the plates. The input voltage required under these conditions is 50 volts for one-inch deflection on the cathode-ray-tube screen.

The machine can be used with the magnetic-type oscillograph if a suitable coupling means is used between the output of the machine and the oscillograph. By using more than one group of three brushes on the commutator, more than one picture can be taken at the same time. Also, more than one commutator can be mounted on the same shaft if more records are required.

Response Characteristics—Input End of Network

Equation 5 (see appendix) indicates that if a wave definition p (number of steps per cycle of highest frequency to be reproduced) is required, the RC product should be decreased as the frequency desired is increased. It is desirable to use as small a value of resistance in the input circuit as possible. If a resistance potentiometer is used to supply voltage

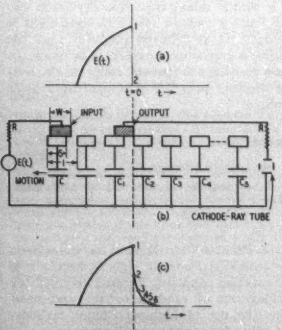

Figure 3. Distortion due to output brush making contact to more than one capacitor at a time

to the network, the resistance of this input device is to be included in determining the frequency response.

It is also advantageous to use a subtended brush angle of such a value that only one or two capacitors are in the brush circuit. The value of C, in equation 5, is the total capacity under the input brush.

It is not difficult to obtain good response as far as the RC value is concerned. The value of p, which determines the definition of the wave, is more important since the maximum frequency which can be transmitted by the network is determined by the number of capacitors required per cycle to make the frequency recognizable in the output circuit. These considerations determine the product pf. After the value of pf is chosen, the maximum value RC, which may be used as far as the input circuit is concerned, can be obtained from equation 5.

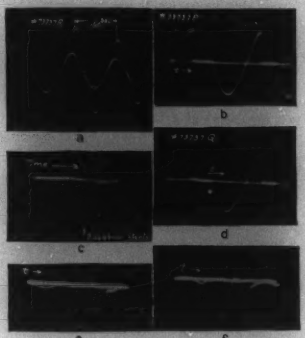

Figure 4. Oscillograms obtained with memnoscope

(a)—60-cycle transient
(b)—Wave as in figure 3a obtained without machine
(d)—Same wave as (b) with machine
(c), (e), (f)—Arc-back oscillograms of anode-to-cathode voltage of a mercury-arc rectifier

The Output End of Network

If contact is made at all times to not more than one capacitor, the output voltage wave into the receiving device will not be distorted provided p, the number of capacitors per cycle, is of sufficient number for the frequency transmitted.

If, however, the output brush makes contact with more than one capacitor at a time, then there will be a division of the charge and distortion will result. The effect of double contact can be seen from a consideration of a wave distribution as shown in figure 3a.

The action is as follows:

At $t = 0$ the voltage on capacitor C_1 (see figure 3b) is E_1. At the time contact is made to C_2, the voltage at the receiving device should be equal to zero according to point 2 on figure 3a. However, if the brush makes contact to C_1 at this time, as well as to C_2, C_2 will be charged to a voltage $E_2 = E^1/_2$. This transfer of charge by the brush continues and a distorted wave as shown in figure 3c will be obtained rather than the correct wave, figure 3a.

If a high-resistance brush material is used, the wave distortion will be reduced. Calculation shows that the resistance through the brush from bar to bar would have to be 1.25×10^6 ohms in order to make E_2 only one per cent of E_1 for the time t_1 used in this machine. A portion of this resistance would occur in the output circuit and distortion there would be enhanced.

Equation 7 in the appendix is for the wave from $t = 0$. This equation indicates that the maximum distortion occurs when contact is made to two bars at a time. For contact to more than two bars at a time, the distortion is reduced slowly; that is, as the log of a function of the number of bars spanned by the brush. Contact to only one bar at a time is best for minimum distortion.

The Short-Circuiting Brush

This brush circuit should have low resistance and inductance. Increasing the number of bars spanned by this brush does not affect the time constant unless the resistance is decreased in proportion. Brushes mounted axially with the commutator and separate and short leads from each brush to the common side of the circuit is possibly the best way to discharge capacitors.

Results With Memnoscope

Figure 4 shows the type of films obtained with the camera using a cathode-ray tube with a blue-trace screen.

Figure 4a shows a 60-cycle transient crossing the cathode-ray-tube screen two times. Each dot on the film represents the voltage of a capacitor.

Figures 4b and 4d are for waves of the type in figure 3a. These pictures were taken, respectively, without and with the memnoscope. They represent the anode-to-cathode voltage of an ignitron operating from a 60-cycle source of power.

Figures 4c, 4e, and 4f are oscillograms of random arc-backs of a rectifier. The films show anode-to-cathode voltage changing from normal inverse voltage to an arc-back. Films c and f show that the arc-back occurs near the crest of the wave, and e shows one starting at one-half crest voltage.

Value of Memnoscope in Research

The memnoscope has proved its value in rectifier research. The opinion has been that arc-banks in rectifiers occurred only during transition time. Oscillograms obtained with the memnoscope show that arc-backs do occur at other times during the inverse cycle. Oscillograms have given information which has led to improved designs and to very substantial increases in the ratings of ignitrons.

Appendix

To determine the frequency response at the input end, we may use the equation for voltage across a capacitor charged through a resistance r. If the input voltage is $E \cos(2\pi ft + \phi)$ the voltage at any time t is, if charge on $C = 0$ at $t = 0$

$$e_c = \frac{E}{2\pi fCZ}\left[\sin(2\pi ft + \phi) - \sin\phi \cdot \epsilon^{\frac{-t}{rc}}\right]$$

where

$$Z = \sqrt{r^2 + \left(\frac{1}{2\pi fc}\right)^2}$$

$$\phi = \psi - \tan^{-1}\frac{1}{2\pi frc} \qquad (1)$$

ψ = phase of E at $t = 0$

In this case the voltage impressed on the capacitor depends on the input voltage at the time contact is made. If the time duration of contact is t_1, when the brush leaves the capacitor being charged, the voltage on the capacitor will be

$$e_c = \frac{E}{2\pi fCZ}\left[\sin(2\pi ft_1 + \phi) - \sin\phi \cdot \epsilon^{\frac{-t_1}{rc}}\right] \qquad (2)$$

t_1, the time duration of contact in terms of the frequency f, and p, the number of capacitors per cycle is

$$t_1 = \frac{1}{pf} \qquad (3)$$

and

$$\frac{t_1}{rc} = \frac{1}{pfrc} \qquad (4)$$

Substituting in (2), e_c becomes

$$e_c = \frac{E}{\sqrt{1 + (2\pi frc)^2}} \times \left[\sin\left(\frac{2\pi}{p} + \phi\right) - \sin\phi \cdot \epsilon^{-\frac{1}{pfrc}}\right] \qquad (5)$$

This equation shows that a phase distortion and an amplitude distortion can occur. Since p must be made sufficiently large to give a recognizable wave, when the frequency desired is increased, the rc value must be decreased in order to make both the second term under the radical and the second term in the brackets negligible compared to other terms in the above equation.

The time of contact t_1, see figure 3*b*, in terms of commutator bar, brush, and insulation dimensions is

$$t_1 = \frac{w + s}{(rps)bl} \qquad (6)$$

Using this value for t_1 we can write (5) in terms of the dimensions, speed, and number of bars.

If contact is made at the output end to more than one capacitor at a time distortion will occur. If we consider an input wave as shown in figure 3*a*, and contact to two capacitors at a time, the output wave will be as shown in figure 3*c*.

This wave can be represented by equation (7), assuming $C_1 = C_2 = C_3$, etc., and a brush of negligible resistance

$$E_n = \frac{E_1}{2^{n-1}} = E_1\epsilon^{-(n-1)\log 2} \qquad (7)$$

where E_n is the voltage of the nth capacitor, and $n = 1$ for C_1, $n = 2$ for C_2, etc., and E_1 = constant. This gives an exponential curve for the output end, instead of a vertical line as desired.

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Discussion

H. P. Kuehni (General Electric Company, Schenectady, N. Y.): In the device described in this paper an electrical phenomenon to be recorded is first impressed on a set of rotating capacitors which are connected to commutator segments. Each capacitor is charged through the input commutator brush to a potential proportional to that of the electrical phenomenon at the time of brush contact. By means of a second commutator brush, which is advanced in the direction of rotation, the charged capacitors consecutively are connected to the oscillograph, thus recording in steps the event a definite time after its occurrence.

The accuracy of reproduction and frequency response of this device are largely functions of the number and size of the capacitors used, the speed of rotation, and the input and output circuit time constants, as well as the energy available from the circuit to be studied. For practical and economic reasons the number of capacitors, commutator segments, and speed of rotation obviously are quite limited. In the author's machine 147 0.01-microfarad capacitors were driven at a speed of 1,800 rpm. Under these conditions a 60-cycle wave is reproduced with 73.5 steps of 4.9 electrical degrees per step. However, a 600-cycle wave, for example, would be reproduced considerably distorted by only 7.35 steps with 49 electrical degrees per step. It is to be expected, therefore, that even though the circuit time constants can be made small to satisfy the response requirements, the limited practical number of capacitors and commutator segments render this type of recording device suitable for moderate frequencies only. It is questionable whether a device of this type can be built economically for high-frequency response as required, for example, in the recording of surges of short duration, switching transients, and the like.

For the recording of random phenomena Doctor A. W. Hull[1] made use of the afterglow of the fluorescent cathode-ray-tube screen. The recording photographic camera, being triggered through a thyratron by the disturbance itself, photographs the afterglow of the cathode-ray trace or the so-called tube screen "memory" of the event. The screen substance willemite, which is widely used in commercial cathode-ray tubes, has an afterglow of approximately $^1/_{20}$ second which is ample time for the camera to catch. An automatic three-tube cathode-ray oscillograph built on the screen "memory" principle has been in continuous and highly successful use for nearly two years in the General Electric Company for the study of random phenomena pertaining to power rectifiers and tube circuits. The cathode-tube screen afterglow can, of course, be used with any cathode-ray oscillograph providing the tube voltage is sufficiently high to produce a recordable trace of the transient. With the General Electric high-speed hot-cathode type-*HC*-15 cathode-ray oscillograph,[2] using a 15,000-volt permanently sealed glass cathode-ray tube, successful photographic memory records were obtained in experimental work of a transient as fast as a 1 × 5-microsecond impulse wave by triggering the camera with a relay energized from a charged capacitor through a thyratron fired by the impulse itself. The cathode-ray tube "memory" principle has practically unlimited frequency response and outside of a simple relay, capacitor thyratron circuit, and a camera, no extra equipment is needed. It is believed doubtful that the author's capacitor device can be made to have as wide a frequency range as the simple memory principle described by Doctor Hull.

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1. See author's reference 2.

2. Electrical Engineering, June 1937, pages 721–7.

W. E. Pakala: Mr. Kuehni has questioned the economical use, at high frequencies, of the rotating capacitor network for memory oscillograms of random events, and mentions the use of high-persistence cathode-ray tubes for memory oscillograms.

The machine described was designed to give information as to conditions existing for two to four cycles prior to random arc-back in a mercury-arc or ignitron rectifier operating from a 60-cycle power source. For these conditions the capacitor machine has been very useful and entirely satisfactory.

In the cathode-ray-tube method of obtaining "memory" oscillograms of random events, it is necessary to keep the tube fully energized and the recurrent phenomena on the screen. This means that the recurrent or normal trace, while waiting for random

Remote Control of Network Protectors

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Synopsis: Two low-voltage a-c networks have been installed in Tennessee, using a radically different protective scheme. The customary master relays, phasing relays, and associated current transformers have been omitted from the network protectors using in their place a remote-control system of pilot wires operated from relays at the supply substation which protect the high-voltage cable feeders.

In contrast with previous pilot-wire-protected network systems utilizing looped primary circuits with secondary transformer fuses[1,2], these networks retain the radial supply and electrically operated secondary air circuit breakers of the more conventional systems.

Previous experience has pointed to operating advantages of a remote control system provided a thoroughly reliable installation could be secured at a reasonable cost. The system described does not exceed the cost of conventional relay installations and it is felt that inherent hazards to reliability have been overcome.

LOAD GROWTH in the business district of Nashville, Tenn., had made necessary the rehabilitation of the existing underground supply system consisting of overloaded 2.3-kv radial cables. Comparative cost estimates showed decided advantage of replacing the entire 2.3-kv system with its crowded ducts and aged cables with a low-voltage a-c network system supplied from four 13.2-kv cable feeders.

Successful operating experience with d-c pilot-wire systems for tie-line protection over a period of five years[3] led to the consideration of remote-control pilot wires for the proposed network system instead of master relays and phasing relays. Conditions particularly favorable to remote control were the fact that an entirely new network system was contemplated making the conversion of existing equipment unnecessary, the supply substation is located immediately adjacent to the network area, the fact that replacement of 2.3-kv cables with 13.2-kv cables would release ducts which would be idle except for remote-control cables, and that the arrangement of duct banks resulted in several "inside" ducts which would be of little use in power-carrying capacity.

Three of the four 13.2-kv cable feeders were connected in service on February 6, 1937, with the initial network step consisting of five units. At the close of 1937 a total of 34 units had been installed on the four cable feeders. Construction is proceeding in a steady program.

In Chattanooga a low-voltage network system is being installed to supplement a 2.3-kv radial underground system. By the end of 1937 a total of eight units had been installed on three 11-kv cable feeders. It is planned that the network will eventually replace all of the 2.3-kv radial underground system.

Operating Requirements

Network experience over a period of years has resulted in a rather imposing list of requirements for the network control relays, such as:

1. The network protector must trip for any short circuit or ground on the high-voltage cable feeder.
2. The network protector should trip on transformer magnetizing current or cable charging current with the supply breaker open.
3. The network protector should not trip due to small phase-angle differences in supply of various feeders.
4. The network protector must not trip during a fault on the secondary network.
5. The network protector must not trip during a fault on any other high-voltage feeder.
6. The network protector should not trip on power reversals at light loads or in case of regenerative loads.
7. The network protector should close when the transformer is energized with voltage of such magnitude and phase relation that power will flow from the transformer to the network.
8. The network protector must not close if resulting power flow would be such as to operate the sensitive tripping relay.
9. The network protector must not pump when the high-voltage cable feeder is energized through one network unit which has failed to open.

It is evident that limits usually imposed on the closing of a network protector are based on imperfect selectivity in its opening characteristics.

A tremendous amount of development work has been done by operating engineers and manufacturers in evolving relays or systems which could meet these requirements, and the remarkably good record of network relay performance[4] is a tribute to their work. One solution[5] has been to apply relays which are sensitive primarily to negative-phase-sequence quantities. Naturally such relays will not meet the requirements of opening on transformer magnetizing current, but operation approaching this can be achieved by providing a source of negative-sequence power at the substation. Another approach[6] has been to install power devices in the primary system for controlling phase-angle displacement of the various feeders supplying a common network. Doubt has been expressed regarding the universal application of either of these methods.

One engineer[7] has compared the operation of a network system to the conventional transmission network in which all switches are operated closed except for inspection or repairs or in event of system trouble, in which case only the circuit breakers which are necessary to isolate the fault are opened. Accordingly it has been suggested that requirements of network relays be reduced to (1) the network protector should close when its transformer is supplied with normal three-phase voltage in excess of the network voltage by a predetermined value (2) the

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The authors wish to acknowledge the assistance and co-operation of the underground distribution, design engineering, and field test personnel of The Tennessee Electric Power Company in the development and testing of this protective scheme, and the co-operation and encouragement of engineers of several utility companies. They also wish to acknowledge co-operation of the engineers of the General Electric Company in furnishing information on various other proposed methods of network protection.

1. For all numbered references, see list at end of paper.

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phenomena, will have some effect on the interpretation of films, since the repeated trace will photograph much better than the transients, which are single sweeps on the cathode-ray-tube screen. In other words, there is some "burning in" effect because of recurrent traces, whereas the intensity of the transient trace decays exponentially.

If a rotating capacitor delay machine is used with a cathode-ray tube, the intensity can be kept at a low level until the camera shutter is opened and high-speed cathode-ray screens can be used, giving pictures of only the trace desired. Another advantage is that a magnetic oscillograph can be used and oscillograms of several currents and voltages obtained simultaneously as economically as with, say, a battery of six cathode-ray tubes.

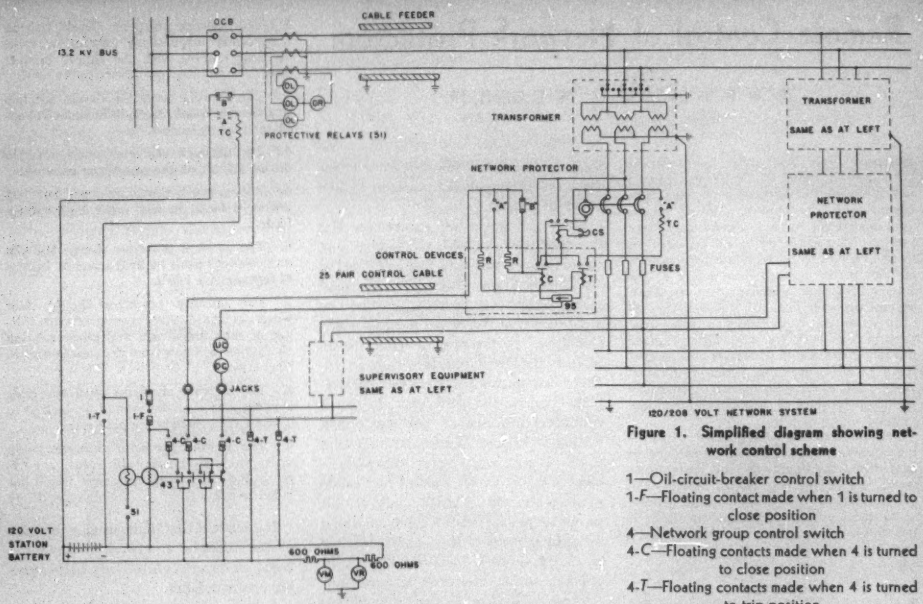

Figure 1. Simplified diagram showing network control scheme

1—Oil-circuit-breaker control switch
1-*F*—Floating contact made when 1 is turned to close position
4—Network group control switch
4-*C*—Floating contacts made when 4 is turned to close position
4-*T*—Floating contacts made when 4 is turned to trip position
43—Series-shunt reversing relay
51—Feeder protective relays
95—Copper-oxide rectifier with mid tap
C—Remote-control closing relay
T—Remote-control tripping relay
CS—Network protector motor cut-off switch
R—4,100-ohm resistor
OC—Overcurrent supervisory relay
UC—Undercurrent supervisory relay
TC—Trip coil
VM—High-resistance voltmeter
VR—Sensitive voltage relay

network protector should trip in case of a high-voltage fault or when opening means are applied at the supply substation.

A network primary feeder with its associated network transformers may be compared to a transformer in a power station which is operated in parallel with other units. Individual control switches provide separate manual control of the high-voltage and low-voltage breakers but internal faults trip both breakers.

This is the general type of control which has been provided for the remote-control network system, except that only two wires are used to connect each low-voltage air circuit breaker with the supply substation equipment resulting in depending on protective relays on a high-voltage feeder alone to determine short circuits in the protected zone.

Description of Control Scheme

Each feeder control panel at the supply substation is provided with two standard-size control switches, one to control the high-voltage oil circuit breaker for the cable feeder and the other to control the entire group of low-voltage network breakers associated with that feeder. Operation of overload or sensitive ground relays applied to the high-voltage cable feeder results in tripping the feeder oil circuit breaker and also tripping the entire low-voltage group, causing green lamps on both control switches to burn and sounding a station alarm which may be silenced by turning both control switches to the trip position. After trouble has been located and repaired the operator can energize the feeder and then close the network switches immediately or if desired he can energize the feeder and wait for a given test period before connecting the feeder to the network.

Among requirements sometimes listed for network master relays is that they shall provide a check on any possible incorrect phasing on the high-voltage or low-voltage side of a network protector during construction. This function is really a by-product of the opening and closing characteristics of the network relays and those who have had experience with incorrect factory wiring of distance relays and similar equipment would not like to trust such devices for a definite check on the adequacy of construction phasing. At the present time our construction forces prefer to check phasing electrically across a network protector with fuses removed but provision has been made for checking phasing of any new network unit or of any splice in a primary cable using equipment at the substation. Instead of using one potential transformer on each underground cable feeder, two such transformers are connected in open delta and a swinging panel with two 360-degree synchroscopes arranged with transfer switches so that a feeder cable may be energized from a new network unit or from a network unit beyond a new cable splice and exact phase relations checked at the substation.

Each primary radial feeder is protected by three inverse-type overload relays with instantaneous attachments and one inverse-type sensitive ground relay with instantaneous attachment (see figure 1). The contacts of all four protective relays are connected to the trip coil of the oil circuit breaker through a series coil of a battery reversing relay. This relay is also provided with a shunt coil which seals in from momentary operation of the series coil until it is released by turning the network group control switch to the trip position. The shunt coil is also operated from a "*b*" finger of the oil circuit breaker

through a floating contact of the control switch, guarding against leaving the primary cable energized from the network (without normal protection) in case the feeder oil circuit breaker should open accidentally.

The reversing relay controls the group of network air circuit breakers on a feeder by reversing 125 volts d-c battery supply to the remote control pairs. Control battery is carried to each network protector on an individual pair of wires by means of number 22 gauge double paper-insulated lead-covered cable located in the same underground duct system with the primary supply cables. For the main runs one 25-pair cable is used with each high-voltage feeder and 10-pair cables are used for lateral runs to each network unit. One common pair for each feeder is terminated in a "condulet" type receptacle at every network protector for plugging in portable telephone equipment. Each control cable has four spare pairs terminated in each network protector.

Inside each network protector housing all relays, current transformers and associated wiring have been removed, leaving essentially an electrically operated air circuit breaker. Two small contactors are added operating in conjunction with one copper-oxide rectifier with mid tap and two fixed resistors to give closing or tripping impulses to the network air circuit breaker depending on polarity of direct current supplied at the substation. As a tripping or closing operation of the air circuit breaker is completed the auxiliary switch inserts a fixed resistance to reduce current in the pilot wire circuit from the operating value to the supervisory value. Figure 2 shows the contactors (*C* and *T*) mounted in the network protector housing. The rectifier and resistors are shown at the lower left. Interruption of d-c supply or the failure of remote-control pairs does not result in operation of the air circuit breakers but merely removes control from them.

Figure 2. Mounting of remote control equipment in standard protector unit

Continuous audible and visible supervision of each pilot-wire circuit[3] is provided by means of a small overcurrent and undercurrent contactor for each pair located at the substation. Remote-control operating current is 130 milliamperes which is reduced immediately through air circuit breaker auxiliary switches to 25 milliamperes. The closing and tripping contactors at the network protectors operate on 75 milliamperes and drop out on 45 milliamperes, while at the substation the overcurrent contactors pick up at 75 milliamperes and drop out at 45 milliamperes and the undercurrent contactor picks up at 18 milliamperes and drops out at 11 milliamperes. A control alarm buzzer at the substation operates if current is above 75 milliamperes or below 11 milliamperes, or in case of a ground on any portion of the battery circuit. A row of telephone-type white supervisory lamps (see figure 3) is provided on the substation feeder switchboard panel with one lamp for each network protector. These lamps burn normally regardless of the position of the network protector but are extinguished if the overcurrent or undercurrent contactors indicate an abnormal condition. Although the alarm system is primarily for the purpose of supervising the remote-control circuits it also calls attention to the failure of an air circuit breaker to open or close (as directed by substation equipment), since the operating current is chosen to pick up the overcurrent contactor.

Under each supervisory lamp on the switchboard panel are located a set of telephone-type jacks for isolation and tests of the individual control pairs. One zero center d-c milliammeter is provided which can be used by means of a cord and plug to read current in any control pair. Thus the operator can determine readily whether an alarm indicates an open circuit, short circuit, or failure of the network air circuit breaker to operate.

An interesting by-product of individual control-circuit supervision is individual remote control of the network protector units. The same telephone jacks used for test and isolation of the control pairs can be used by means of a special plug to operate one or more network units to a position other than that indicated by the principal control switch. When the special plug is removed from the test jack the network protector returns to the position called for by the main control switch. Naturally the automatic battery reversing relay takes precedence over the individual jacks as well as over the main control switch, so that network protectors always trip in case of power trouble regardless of manual operation from the substation.

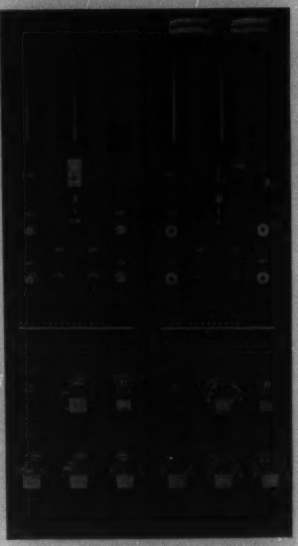

Figure 3. Switchboard arrangement of control equipment for Nashville network. Each panel controls one primary feeder and its network protectors

Figure 4 shows a front view of switchboard at the supply substation of the Chattanooga network. The control scheme is quite similar to the Nashville installation except that a row of keys has been provided for individual control of the network units using jacks merely for tests and isolation. A further difference is that the single white supervisory lamp for each network protector has been replaced by a supervisory red lamp and a green lamp, these lamps being operated from the same contacts on the overcurrent and undercurrent relays which are used in the Nashville scheme to operate the white supervisory lamps. The red and green lamps are connected at the substation end of the remote control pairs (between substation battery and the supervisory relays) so that a somewhat better indication of the position of the network protectors is given as long as the control circuit is intact and the protector operates correctly. Naturally complete indication

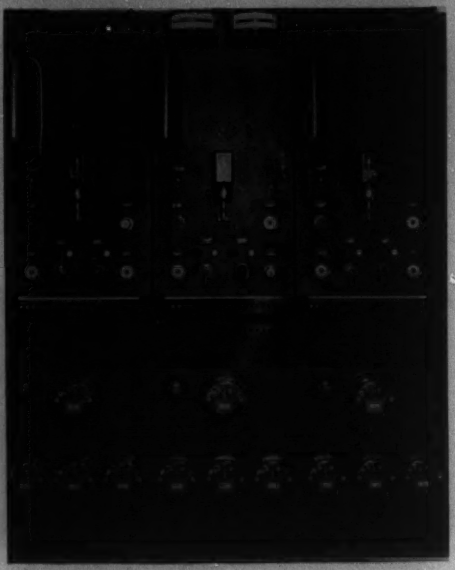

Figure 4. Switchboard arrangement of control equipment for Chattanooga network. Each panel controls one primary feeder and its network protectors

of the network switch position with the control circuit in trouble would require additional control wires. If the control pair is in trouble or if the network protector fails to move to the required position then the red and green lights at the substation burn dimly in series.

It may be noted that telephone type equipment has been mounted on the standard ebony asbestos switchboard by using a center section of thin bakelite arranged flush with the front of the $1^1/_2$-inches-thick composition panel.

Relative Cost of Remote Control Equipment

At the present time standard network protectors without relays or current transformers are being purchased from two leading manufacturers with a price reduction of about $400 per protector. Estimates based on the Nashville completed network with a total of 60 network protectors show that the pilot-wire cables and associated equipment can be installed for about 60 per cent of the price reduction on the 60 network units. These estimates include cost of the control cable and its complete installation with fireproofing but do not include any allocated cost for duct space. No credit is taken for the cost of telephone pairs. Cost of terminal equipment in the network protectors and at the substation is included. Many of the parts are quantity-production items used in communication and automatic control.

In cases where duct space for control-cable circuits is not readily available at moderate cost, consideration should be given to leasing a remote control pair for each network protector from the local communication company. Aside from the cost comparison, the advantage of relative freedom of exposure to power system troubles can be weighed against possible control-circuit outages arising from telephone protective equipment or maintenance procedure on the part of the communication company.

While variations in cable installation cost may be expected the resulting figures would still show positively that the remote-control system would not cost more than the conventional system. The fact that the selling price of the equipment omitted from the network protectors is nearly $600, whereas the present omission price is two-thirds as much points to probable additional economies in the future.

Reliability

It is generally conceded that the frequency of inspections of equipment which is likely to cause trouble has a pronounced bearing on the probability of failure of protective equipment to perform properly during system trouble. Attention has been called to this recently in connection with low-voltage a-c network operation.[4] Experience with transmission relays has emphasized the need of frequent inspections of protective devices and in the case of protective equipment which is difficult to inspect and which is exposed to hazards extending over several miles such as a pilot-wire circuit the use of continuous audible and visible supervision has been found highly effective. Although these conclusions were reached through operating experience and study, the curve of figure 5 has been prepared to illustrate the theoretical relation between the time required to locate and clear protective trouble and the probability of failure of the protective equipment to clear primary short circuits. The time of one hour at one end of the curve is taken as a typical value for remote-control equipment since within this length of time the operator can determine that an individual control pair is defective (grounded, short-circuited, or open-circuited) and can arrange to have this individual network unit removed from service even under peak load conditions such that it would be undesirable to remove an entire network feeder from service.

Experience of communication companies indicates that many troubles with underground lead-covered cables come about through the entrance of moisture into the cable through small defects in the lead sheaths. Several hours are usually required after the failure of one pair before the entire cable is involved. This was borne out in striking manner by the one case of control-cable trouble which has been experienced since the Nashville network system was started. A splice was known to be defective (due to special local causes) but construction was at such a stage that it was decided to leave the splice in service over a period of time and observe results. After the first pair caused operation of an overcurrent relay (indicating a high-resistance short circuit) a period of six days elapsed before another pair was involved. After an additional period of 12 days two other pairs were involved and at that time the defective splice was repaired. This trouble was due to the entrance of moisture through a defective splice into one of the 25-pair control cables.

Another case of trouble was discovered by means of the ground alarm. Isolation of various pairs at the substation by means of test jacks immediately located the faulty circuit which was then operated to trip the network protector and isolate it from battery supply. An investigation showed a vault half full of water and a defective network-protector housing had

permitted moisture to collect on the control wiring resulting in the indication of a high-resistance ground.

The adequacy of supervision for preventing protective failures rests on troubles in the primary equipment and control equipment being reasonably independent of one another, and precautions have been taken to insure this condition. Special short-circuit tests were made to determine the possible difference of ground potential between the supply substation and network units from which calculations indicate a maximum difference of 200 volts under the most unfavorable short-circuit conditions.

One chief cause of concern has been the likelihood of primary cable burning control pairs in two or destroying a network control cable. The choice of control scheme has reduced the possible damage from such a contingency. In case of a primary cable burning its associated control cable, correct operation is secured if the tripping impulse is given to the network protectors before any control cable

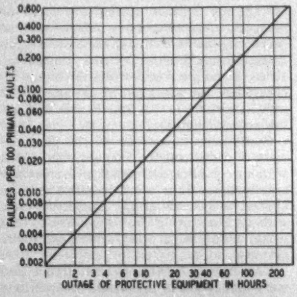

Figure 5. Curve showing probable failures per 100 primary feeder faults of network protector units to trip due to control pair and control equipment failures extending over various periods of time

pairs are damaged. The use of instantaneous devices on the protective relays and high-speed control equipment insures that the trip plungers at the air circuit breakers will be in motion less than four cycles after the beginning of the fault. Since interruption of d-c supply does not cause the network protectors to open, the damaging by a power cable of a control cable associated with another feeder does not impair operation as long as the control cable can be repaired and restored to service before the occurrence of a second high-voltage fault.

In order to minimize the possibility of any damage to control cables from power equipment the control cables have been fireproofed at every vault in the same manner as the power cables and wherever feasible they are located not too close to the power cables or splices. As a check on the adequacy of such fireproofing, short-circuit tests were arranged at system voltage, using short sections of three conductor power cable and splices of such cable placed within five inches (surface to surface) on racks from a section of fireproofed control cable. An internal fault from one conductor to sheath was made before the test in each sample of cable and oscillograph elements arranged to record any change in normal direct current in any pairs of the control cable and also to record through a current transformer the passage of any current to the sheath of the control cable.

A series of 15 short-circuit tests were made energizing the faulted cable specimen with a three-phase grounded-neutral 11-kv power source of sufficient capacity to provide a ground current of 7,000 amperes. The duration of these short circuits was varied from 5 cycles to 30 cycles and in no case was there any disturbance to the control current and in none of the tests did the arc cause any current to flow in the control-cable sheath. Figure 6 illustrates the arrangement of test cables and shows burning of adjacent surfaces after a short-circuit test.

The extremely remote possibility of an entire control cable being out of service during a primary fault was examined by calculating the division of fault current through the entire network with a short on a primary feeder. Studies showed that all protector fuses on the faulted feeder would blow without damage to equipment. This situation should apply to any network designed for adequate burn-off characteristics.

Many failures of network protectors to clear primary faults are due to troubles in the network protector mechanisms. Since more than one-half of all network operations are classed as "miscellaneous" or unintentional[4] a control system which eliminates practically all of such operations should result in improving the performance records of network protector mechanisms for the same frequency of maintenance.

Maintenance

All devices have been applied with ample margin, especially those located inside the network protector housings. For example, the continuous current through the copper-oxide rectifier is less than 25 per cent of the rated current of this unit. The normal rectifier resistance is under 10 per cent of the total series circuit permitting wide variations with temperature without seriously affecting the value of operating current. Although it is not required for reliable action, the pilot wire operating current may be held within 10 per cent of its rated value by means of tapped resistors located in the substation even if aging of a rectifier unit should raise its forward resistance to as much as five times the normal value. It is evident that there are no fine adjustments to be made to the protective equipment even on the more accessible apparatus located at the substation. Protective maintenance then becomes primarily a matter of repairing any failures in the control cable.

A control system which eliminates practically all unintentional protector operations should reduce trouble and expense of maintenance on the network protector mechanisms. It has been noted on power systems that an oil circuit breaker which is approaching a stage of uncertain operation due to sticking, weak springs, wearing of latches and rollers, or similar causes will frequently give forewarning of such a condition by operating sluggishly on the tripping operation if it has been standing closed for sometime (although subsequent operations for tests may be at normal speed), or by failing to

Figure 6. Tests illustrating integrity of remote control when exposed to a 7,000-ampere short circuit on adjacent power cable

latch on the first attempt to close it. It seems entirely probable that a system which calls audible and visible attention of the operator to any initial failure to latch or to any sluggishness in open ng of a particular network protector will aid in a program of maintenance which should forestall many mechanical failures.

In contrast with a remote-control system the conventional network-protector relays must be adjusted very closely and slight variations in their characteristic due to temperature, corrosion, and loose connections, are quite serious. Many have found the maintenance and tests of network relays to be extremely difficult when performed at the network protector location[8] and two leading manufacturers now supply readily detachable relays so that these may be checked in the laboratory and then installed in the network protectors.

Additional Operating Features

Design of protective equipment has been concentrated on securing a thoroughly reliable installation at reasonable cost and it is planned that no other features will be added until after considerable experience and study of the present installations. However consideration may be given in the future to the installation of temperature and pressure relays in each network transformer using existing remote-control pairs. One possibility would be to permit the temperature and pressure contacts to send an alarm or tripping impulse over a common pair for all the units on one feeder cable with auxiliary contacts to trip the protector at the transformer involved and open its d-c control circuit thus providing instantaneous indications at the substation of the number and location of transformers involved without the use of coding. Consideration has sometimes been given to differential protection of network transformers but there has been no means of tripping the high-voltage feeder in case of low-voltage transformer trouble. One common pair for each feeder could be used for such a purpose, using the individual control pair for indicating the location of the transformer which had caused the feeder to trip.

Individual control of the network units can be used to considerable advantage without installing additional equipment. Consideration is being given to the installation at the substation of three sensitive single-phase wattmeters of low current range which may be connected to the current transformers on any feeder by means of transfer switches. Auxiliary current transformers would be connected wye-delta and used to bring wattmeter current in phase with current at the network-protector terminals. After a secondary fault or on any routine basis the operator can open a group of network protectors associated with the feeder and then close one of them with individual control jacks. The wattmeters may then be switched to the feeder supplying the one network unit and wattmeter readings would instantly show if there were any fuses which had blown during secondary trouble or due to mechanical defects.[9] Readings could be taken one at a time on all the network units on one feeder in a few minutes. Such a procedure would also indicate possible overloads on any transformer unit. This scheme has been tried using a special portable wattmeter and indications of a blown fuse are quite positive. Readings obtained from this method from the substation on individual units check very closely with current readings taken at the vaults.

Conclusions

1. The remote-control system described can be applied to the protection of many network systems at reasonable cost and in some cases at a substantial saving in cost over systems with conventional relays.

2. The remote-control system offers distinctive advantages in simplicity, flexibility, freedom from pumping, decreased maintenance trouble and expense on relays and protector mechanisms and suitability for a wide range of supply systems.

3. Operating experience must provide the final proof of the adequacy of any protective system, and the relatively low rate of primary failure on an underground network may require that such operating experience continue over a period of several years for conclusive results. Nevertheless it is felt that careful consideration has been given to all features and that operating and short-circuit tests have been carried far enough to predict excellent operation. Previous experience with pilot-wire circuits and their supervision points toward a protective design of high reliability.

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8. Operating Experience With the Low-Voltage A-C Network in Cincinnati, **F. E. Pinckard**. AIEE Transactions, volume 48, 1929, pages 896–901.

9. Discussion by **J. S. Parsons**, AIEE Transactions, volume 56, 1937, page 1031 of a paper entitled A New Thermal Fuse for Network Protectors, **L. A. Nettleton**, AIEE Transactions, volume 55, 1936, pages 1096–9.

Discussion

L. H. Hill (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): Messrs. Brownlee and Dent have developed a low-voltage a-c network system devoid of all sensitive and unnecessary relays, without sacrificing the flexibility of the more complicated automatic non-pilot-wire control systems. In addition it provides the means for controlling the operation of any one of the switches between the transformer and the low-voltage mains.

Continuous supervision of the pilot circuits, and their subdivision into small parts, without complication, should prove entirely satisfactory. It is a scheme that may be applied to systems of any primary voltage without introducing the complications that would follow with other known pilot-wire systems.

The Brownlee-Dent system should find wide application in the smaller areas where the cost of duct space is nominal or of course also in larger areas if pilot wires can be economically installed.

J. B. Hodtum (Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.): From a description of the authors' pilot-wire-controlled system, it appears that they have greatly simplified the operation of low-voltage a-c network systems. The third conclusion of their paper will really prove the merits of this system.

There is some background of course for the use of pilot-wire-controlled circuits as they have had wide use in Europe, especially in England. It seems that the authors have taken every possible precaution to supervise continuously and to guard against failure of any part of the control system involving the entire feeder. As pointed out, the control system may be extended to include, for example, differential protection of individual transformers which may even be made automatically to disconnect a feeder. It is questionable, however, whether automatic tripping of a feeder due to trouble, in a single unit, is advisable.

It appears that this system may be an advance in the art in that it permits individual transformers to carry loads in the reverse direction, since such operation would really mean that energy is being transferred from one part of the low-voltage system to another part over the high-voltage feeders instead of through the low-voltage network itself.

E. E. George (Tennessee Electric Power Company, Chattanooga): The authors have touched lightly on several important features of this new remote-control system. One feature is the possible use of control cables leased from a communication company. In Chattanooga and Nashville it was found that the telephone company could reach each transformer vault with a control pair over an underground route separate from the power route. This installation would usually be through the building adjacent to the transformer vault. However, the availability of a large amount of excess duct space made power-company-owned control cables somewhat cheaper.

If the communication company could establish a group rate for several pairs in the same area or in the same cable, avoiding long central-office loops there ought to be a considerable field of future business in certain cities that might use this new network control.

A feature that has appealed strongly to the operating, maintenance, and construction departments has been the availability of telephone service in each transformer vault. The portable telephones used by the underground crews and test engineers are furnished by the telephone company and permit ready communication between vaults and with the distribution dispatcher, assistant dispatchers, maintenance supervisors, and all other points.

This new system with its manual group or individual control of protector opening and closing by the operator at the supply station may be attractive to the metropolitan companies requiring sectionalizing in case of shutdown. We would like to have comments from those more familiar with this problem. Although about everything possible has been done to test out the new system, the real test will be the emergencies that may occur in the future without engineering, test, dispatching, and maintenance departments right on the scene. Such emergencies occur rarely, and it is hoped that other companies will make installations of this type of remote control so as to expedite the development work and to provide service for the benefit of the industry in general.

L. F. Kennedy (General Electric Company, Philadelphia, Pa.): The authors have made the statement that the limits placed on the closing characteristic of the network relay are due to the imperfect selectivity of its tripping characteristic. I should rather say that all the limits under which the network relay must operate, either to trip or reclose, are brought about by combining in one device both protective and control functions. It naturally follows that the device which meets these requirements needs more maintenance to insure reliable operation. The authors' familiarity with other protective relays will bear out the statement that as the operating requirements become more severe, the maintenance is increased.

The authors have installed the pilot-wire system at a saving in cost over the conventional network protector. At the same time they indicate savings in maintenance through the use of their system. But this has been done by setting up a new set of requirements, or rather the waiving of some of those normally met by low-voltage network protectors, and it would seem proper that any economic comparison then should be made between a network protector and a pilot system fulfilling the same requirements.

Relay equipment to trip on feeder faults only would be relatively simple, and if reclosing were permitted whenever the feeder voltage is approximately normal (corresponding to primary network practice), the over-all relay picture would be considerably changed. With such equipment relay and protector maintenance could be reduced and, since the protectors would operate only under short-circuit conditions, longer life would be obtained.

The pilot system operates basically in the same manner as the protector but in addition provides continual indication of each protector position and permits manual operation of the protectors either singly or by groups. The value of indication and control, even if considered to be small, is an item favorable to the pilot system.

It would seem necessary, therefore, to draw up a new set of operating requirements wherein the desired relay characteristics are definitely shown and then compare installed cost and maintenance of the two systems. If on such a comparison the pilot system is shown to be less expensive, it can unquestionably be justified. If the pilot system is more costly, it may still be justified by evaluating the indicating and control features.

I have purposely omitted any consideration of relative reliability in the foregoing comments. With simpler relay equipment I should be inclined to consider it more reliable than the pilot, but this is admittedly largely my own personal opinion. Certainly experience of the past few years has demonstrated that a pilot system of this type will show a high degree of successful performance. Given an equal amount of experience with both systems, perhaps the reliability should be considered equal.

To me the successful operation of the authors' system opens up the whole question of operating requirements of low-voltage networks. It is perhaps possible that these requirements have been made too severe and that we may see in the near future a general lessening of them accompanied by a reduction in maintenance expense on the whole system.

F. Von Voigtlander (The Commonwealth and Southern Corporation, Jackson, Mich.): The system of remote control of network protectors described in this paper appears to be a considerable advance in control systems of this type, and at the same time it achieves that goal sought by all of us, that of obtaining something better at a lesser cost compared to conventional methods.

The installation cited for a basis of comparative costs, involves a total of 60 network-protector units. There is, no doubt, a minimum system to which it would be economical to apply a network control scheme of this type. I would like to ask the authors' opinion of the approximate size of such a minimum system.

T. G. LeClair (Commonwealth Edison Company, Chicago, Ill.): A pilot-wire scheme for the control of network protectors is naturally of more interest to a Chicago engineer than any other because the Commonwealth Edison Company has made wider use of pilot-wire relay protection than perhaps any other metropolitan utility. Also, the operating record of the pilot-wire relaying system has been much better than that of other relaying systems. For many companies the cost of the pilot-wire control scheme for networks would be materially increased because of the duct cost which must be added to the cable cost. However, for larger cities a majority of the pilot cable would be installed in large duct sections where the central ducts cannot be used for power cables due to temperature limitations, but are available for pilot or control cable. Therefore, a large part of the duct cost charged to the pilot cable would be more theoretical than real.

The pilot-wire system suggested by Messrs. Brownlee and Dent might even be extended to include greater protection than at present by the addition of differential relays on the network transformers and a tripping circuit which would trip the primary and all the secondary breakers automatically for a fault on the transformer secondary in the zone now unprotected.

One missing feature of the scheme suggested in the paper is the inability to trip on back-feed through the network units without the use of the control equipment at the supply end. This is probably only of importance for a system fed from two independent sources where it is desirable automatically to transfer the entire network load to one source in the event of a major catastrophe which would make the feeder circuit breakers inoperative due to fire or explosion in the other source.

An item of maintenance expense which might be important in metropolitan systems is the relatively large number of cable cutovers which would be necessary on the pilot cable as the network system grows and transformers are frequently transferred from one feeder to another, either singly or in groups.

Chase Hutchinson (Tennessee Public Service Company, Knoxville): This type of system should appeal to many operating men since it offers a means of securing almost any desired information on vault conditions and at a low cost. Load, temperature, pressure, and other indications of condition can be transmitted, either to inform the operator, trip the vault protector, or trip the entire circuit. It eliminates much of the loss of time in checking protector positions and almost immediately locates a protector which sticks in the closed position.

Balancing some of these attractive advantages are some disadvantages the writer believes deserve careful consideration:

1. What is going to happen if a street cave-in or duct-line failure occurs? Can the network system

be depended upon successfully to blow simultaneously the required number of protector fuses?

2. In most cases the question of duct cost for the pilot cable cannot be neglected.

3. Since the pilot wire cost varies with the length of the feeder, and the network relay cost varies with the number of transformers, it appears the "beginning" cost of the pilot wire system might be higher than the conventional protector.

4. In attempting to peer into the future capital cost of these systems, one is inclined to argue thus: The pilot wire system is largely made up of "production items," and to a considerable extent is assembled in the various transformer vaults and manholes. The cost of this type of work is apt to increase in future years. On the other hand, the conventional protector has had to stand an enormous development and advertising cost. The present version is reliable, and with general acceptance of the system at hand it seems reasonable to believe the cost of protectors will decrease in the future years.

5. The spot network using pilot-wire protectors may be prohibitively expensive.

It appears to the writer that the system devised by Brownlee and Dent is comparable to the conventional network protector system equipped with supervisory control, consequently, where supervision of the protector and vaults is considered necessary, the scheme appears to offer a lower cost method.

J. H. Neher (Philadelphia Electric Company, Philadelphia, Pa.): The use of low-voltage a-c networks is in general limited to relatively large urban load centers, and as a result not many relay engineers have need to study this phase of the relay art. Despite this fact, however, all relay engineers can well profit by a careful study of this paper. The straightforward manner in which the authors, unencumbered by previous notions as to how network feeders could be relayed, have produced a new system, designed from the ground up to do the specific work at hand, should be a good guide in the design of other types of relay systems.

The authors' tests demonstrating the independence of the control circuits with respect to short circuits in the power circuits, are most interesting. The results of these tests, together with the relatively low cost of installation of the control cables, open up a large field for the use of power company owned-and-installed communication circuits for relay protection and remote control.

W. R. Brownlee and W. E. Dent, Jr.: The beginning cost of a remote-control network system will naturally be greater per network transformer than the complete installation as pointed out by Mr. Hutchinson. The answer to this question and also to Mr. Von Voigtlander's question concerning the minimum size network system to which remote control could be applied economically is best given by considering specifically the present status of the Chattanooga network. The control equipment cost per network transformer is determined partly by the fixed terminal cost at the substation, but more by the length of control cables as determined by the distance from the supply station to the beginning load center. In the case of the Chattanooga network the supply substation for the present three-cable system is 0.8 mile from the load center of a small area, resulting in a control equipment cost of almost exactly the value of the price reduction of the network protectors. The demand of the present Chattanooga network is 1,500 kw which could be considered as the minimum system (based on cost alone) with the supply point approximately one mile from the load center.

As pointed out by Mr. LeClair and Mr. Hodtum the remote-control system lends itself to the ready application of differential protection of network transformers. In conventional systems the protectors or backup fuses will usually separate the network from a short circuit on the secondary of a transformer but proper co-ordination of the high-voltage feeder relays prevents automatic disconnection of the primary feeder in case of transformer secondary trouble. Probably protection of this zone has been omitted due both to the inherent difficulty of such protection and to the infrequency of transformer faults involving the secondary only.

The authors do not agree altogether with Mr. Hodtum that differential protection of network transformers should merely sound an alarm at the substation. Present remote indicating equipment transmitting indications of over-temperature or over-pressure of a network transformer do not usually trip feeder breakers, since their indication is not altogether positive and since it may indicate merely a secondary fault between turns which would gradually build up pressure over a period of minutes or even hours. Since most of these present systems are looped through all transformer vaults and depend on coded signals for determination of the transformer in trouble they are not suitable for instantaneous disconnection of a feeder if such were desired. It is the authors' opinion that any fault in a transformer sufficient to operate a differential relay requires immediate action and should be disconnected within a few cycles. Probably the general application of differential protection will be governed by the frequency and seriousness of faults beginning on transformer secondaries and also by the effectiveness of temperature and pressure devices, many of which have been installed in the last three or four years.

Mr. LeClair raises a pertinent question in cases where a network is supplied from two or more busses in the same or different substations. Naturally a major failure of a feeder oil circuit breaker could prevent this breaker from clearing a short circuit or even from opening mechanically. Usually differential or backup-type bus protection will be employed to disconnect all sources of power from the bus and extra contacts of the bus protection auxiliary tripping relay should be connected to the shunt coil of the reversing relay (device 43 of figure 1) of each feeder, thereby preventing the network from feeding the short circuit regardless of the condition or position of the feeder breaker.

Mr. Hutchinson's question regarding duct-line failures apparently considers a serious and infrequent disturbance of such a nature as to destroy first one or more control cables and second the power cables associated with those particular control cables. The calculations mentioned in the paper in connection with this extremely remote possibility considered a fault on one of the three or four primary cables with its protection completely removed and it was found that the backup fuses would operate without damage to equipment. These network systems have not been designed to operate with two cables out of service on a three-cable or four-cable system and consequently no studies have been made of simultaneous faults on two or more primary cables with protection previously removed.

Mr. LeClair's question regarding maintenance expense of transferring control cables when network transformers are transferred from one feeder to another is rather difficult to answer. Obviously a reconnection of cables at the network units would involve appreciable maintenance expense. One possibility would be to leave the secondary cables connected at the network transformer end and merely exchange pairs between adjacent control panels at the substation end. Proper coding of the control cables would permit ready identification of pairs from a key drawing showing the routing of each separate control pair. The result of having three or four pairs of one feeder located in the 25-pair control cable for another feeder is not as serious as it might seem. The resistance of terminal equipment at the substation in series with each control pair is enough to limit short-circuit current in a control cable to a few tenths of an ampere. The voltage on the pairs is maintained at approximately 65 volts to ground through a resistance of some 40,000 ohms (see figure 1). Furthermore the accidental short-circuiting, open-circuiting, or grounding of a control pair does not result in improper operation of any network protector and accordingly all construction splicing and maintenance of control cables can be made if desired without removing battery supply from the cables.

The authors cannot agree with Mr. Kennedy that any network operating requirements have been waived, but are convinced that the long list of requirements of conventional relays are solely for the purpose of fulfilling properly the simple operating requirements outlined in the paper. Even if operators were willing to waive the disconnecting function of network protection, and send a man to each vault whenever a clearance is required, it is doubtful if much simpler equipment can be readily designed to trip on feeder faults only. That is, conventional relays set insensitive enough to prevent improper operation on various power reversals might not be sensitive enough to operate in case of a ground on a primary cable using customary delta-wye network transformers and shielded primary cable. The authors are pleased to have a manufacturer who sells large numbers of network protectors confirm their opinion that protector maintenance will be reduced and operation improved if all "miscellaneous" or unnecessary operations are eliminated.

Positive-Grid Characteristics of Triodes

By RICHARD W. PORTER
ASSOCIATE AIEE

Synopsis: The total emission current in a vacuum tube can be expressed by the familiar space-charge equation. This paper shows theoretically that the ratio of plate current to total current should be a function only of the ratio of grid to plate voltage, and introduces experimental data to show that the function can be represented by a single exponential term. The exponential function is combined with the space-charge equation to obtain an empirical equation for the positive-grid plate-current characteristic. A simple, experimental method of obtaining the constants in this equation is described.

THE NEED for higher efficiency in radio-frequency power amplifiers makes it desirable to operate vacuum tubes with grids strongly positive for a short interval in each cycle. When the grid of a tube becomes positive, not all the electrons which leave the cathode will go to the plate; some of them will be collected by the grid. Therefore, the plate-current equation[1] which has been used for negative and low positive grid potentials assuming negligible grid current, will not apply. This paper presents a modification of the usual equation which takes account of the division of current between grid and plate. The object is to obtain a simple expression which will give approximately correct values of plate current when the grid is strongly positive, rather than to attempt to analyze in detail the various phenomena which occur within the tube.

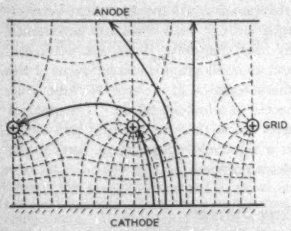

Figure 1. Possible electron paths in tube with positive grid

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RICHARD W. PORTER is employed in the engineering general department of the General Electric Company, Schenectady, N. Y. This paper is part of a dissertation presented for the degree of doctor of philosophy at Yale University.

1. For all numbered references, see list at end of paper.

Total Space Current

It has generally been assumed that the basic space-charge equation

$$i = k(e_p + \mu e_g)^n$$

holds equally well for both positive and negative grid potentials, provided the current i includes all the electrons which leave the cathode, both those that go to make up the grid current and those that go to the plate. This assumption follows from the usual derivations based on the work of Langmuir[2] and Van der Bijl,[3] provided there be sufficient emission from the cathode to maintain the space charge, and that there be no unusual interaction between electrons after they leave the cathode space-charge region. Its validity is strikingly illustrated by the constancy of the total current in the following data for the Radiotron *UV* 207 in which grid and plate voltages were varied holding constant the sum of the plate voltage plus the grid voltage times the amplification factor.

The equation for the total space current can therefore be written

$$i_p + i_g = k(e_p + \mu e_g)^n \qquad (1)$$

where k, μ, and n are constant and have the same values when the grid is positive as when it is negative.

Division of Current Between Grid and Plate

In considering the problem of current division between the grid and the plate, first examine the path of a single electron which is emitted from some point on the cathode with negligible velocity. It will move as shown in figure 1 through a complicated electric field pattern, perhaps reaching the grid, perhaps the plate. If the grid and plate voltages are increased but kept in the same ratio, the magnitude of the field at any point will increase, but the field pattern will remain the same. Under these conditions, it seems reasonable that the electron paths also should remain the same, although the velocities may increase. This fact is proved mathematically in appendix *A*. The destination of any particular electron, therefore, will depend only on the ratio of the grid voltage to the plate voltage.

Generalizing from the single electron to many electrons, there follows the important conclusion that the division of current between grid and plate should be a function only of the ratio of grid to plate voltage, and for any given ratio should be independent of the magnitudes of these voltages. The assumptions implied in this generalization are, (1) no emission of electrons by grid or plate, (2) no interaction between electrons after they leave the cathode space-charge region, (3) negligible initial velocity, (4) no interaction between the electrons and gaseous molecules. The nature of the functional relationship must be such that the ratio of plate current to total current will be unity when the grid voltage is zero, and will approach but never become zero as the ratio of grid to plate voltage becomes large.

Experimental Data

Data taken by the writer for the type-46 tube at high positive grid voltages tend

Table I

e_p	e_g	$e_p + \mu e_g$	i_p	$i_p + i_g$
500 v	500 v	10,500 v	2.3 a	3.35 a
2,500	400	10,500	3.1	3.20
4,500	300	10,500	3.25	3.25
6,500	200	10,500	3.30	3.30

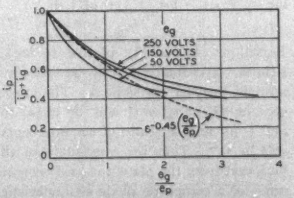

Figure 2. Current division in type-46 tube with grids connected together

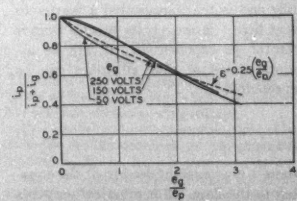

Figure 3. Current division in type-46 tube with grid 2 connected to plate

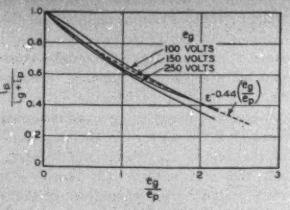

Figure 4. Current division in Westinghouse EX 50 50-watt triode

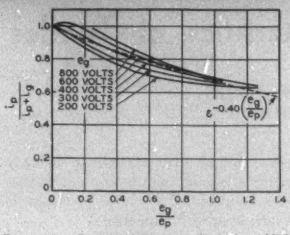

Figure 5. Current division in Radiotron UV 207, SKW triode

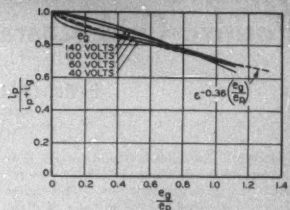

Figure 6. Current division in General Electric FP 169, 150-watt triode

to confirm these predictions and at the same time to justify the assumptions on which they were based. See figures 2 and 3, in which the ratio of currents is shown as a function of the ratio of voltages for various values of grid voltage. Except for the secondary effects which were assumed negligible, all the curves for each tube should be exactly the same. Similar curves have been plotted from data taken by Kozanowski and Mouromtseff[5] for the Westinghouse *EX* 50 tube and from published data on various RCA and General Electric tubes. Of these latter the *UV* 207 shows the highest discrepancy and the *FP* 169 the least. It is significant that the *UV* 207 characteristics show large secondary emission currents from the grid, particularly in the region of largest discrepancy, whereas secondary emission is not prominent in the *FP* 169. Data for the *EX* 50, the *UV* 207, and the *FP* 169 are shown in figures 4, 5, and 6.

These comparisons lead to the conclusion, perhaps already foreseen, that secondary emission is the principal reason for the failure of the current ratio to be a simple function of the voltage ratio. However, the greatest divergence observed was only about 17 per cent, or nine per cent variation from the mean. For the region near $E_g = E_p$, the greatest variation to be found in the published data is less than four per cent from the mean. Errors in measurement and drafting are sometimes as great as this.

The exact nature of the relationship between the current ratio and the voltage ratio depends on the construction of the tube and is too complicated a matter to treat here. However, its general form is that of an exponential. It will be assumed therefore that all tubes can be represented by

$$\frac{i_p}{i_p + i_g} = \epsilon^{-\alpha\, e_g/e_p} \qquad (2)$$

where α is a constant used to fit the equation to the data. For practical purposes it is usually well to choose α so the curve will match the data at $e_g = e_p$, for it is in this region that a tube delivers most of its useful power as a high-efficiency radio-frequency power amplifier. Representative exponentials are shown in dashed lines in figures 2 to 6. The error in this assumption is seen to be approximately the same as that introduced by assuming the existence of a simple functional relationship between ratios.

Plate Current

Combining the expression for total space current (1) with that for the fraction which goes to the plate (2), we obtain an equation for the plate current alone

$$i_p = k(e_p + \mu e_g)^n \epsilon^{-\alpha\, e_g/e_p} \qquad (3)$$

This equation as it stands is correct only when e_g and e_p are both positive. When the grid is negative the exponential term remains equal to one and when the plate is negative, it is zero.

It is not necessary to have complete oscillographic data on a tube in order to evaluate the constants of equation (3). They can be determined by a few simple measurements of plate and grid current at low voltage. For the composite diode characteristic $e_g = e_p$ equations (1) and (3) become

$$i_p = k(1 + \mu)^n e_g^{\,n} \epsilon^{-\alpha} \qquad (4)$$

$$i_p + i_g = k(1 + \mu)^n e_g^{\,n} \qquad (5)$$

Taking the logarithm of both sides,

$$\log i_p = \log \{k(1 + \mu)^n\} + n \log e_g - \alpha \qquad (6)$$

$$\log (i_p + i_g) = \log \{k(1 + \mu)^n\} + n \log e_g \qquad (7)$$

Equations (4) and (5), plotted to logarithmic co-ordinates, will be parallel straight lines having slope n. The intercept of (5) at $e_g = 1$ will be equal to $k(1 + \mu)^n$ and the ratio of the intercepts will be $\epsilon^{-\alpha}$. Thus the constants can all be found from the plate and grid current data for a composite diode characteristic and the value of μ, which may be determined in any of the usual ways.

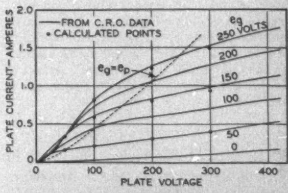

Figure 7. Positive-grid plate characteristic of type-46 tube, grid 2 connected to plate, showing comparison with calculated points

Figure 7 shows the agreement between equation (3), with constants determined by the composite diode characteristic, and an oscillographic measurement of the characteristics of a type-46 tube connected as a low-mu triode. The greatest error is less than ten per cent and occurs in a relatively unimportant part of the characteristic.

Grid Current

Subtracting equations (1) and (3) the grid current is found to be

$$i_g = k(e_p + \mu e_g)^n [1 - \epsilon^{-\alpha\, e_g/e_p}] \qquad (8)$$

When the constants for this equation are determined from the diode characteristic, it will hold very well for points near $e_g = e_p$ where the grid current is large. Although not nearly so accurate as the plate-current equation, the grid-current expression is a welcome aid in approximating the grid current and driving power in radio-frequency amplifiers.

Summary

It has been shown that the equation

$$i_p = k(e_p + \mu e_g)\epsilon^{-\alpha\, e_g/e_p}$$

will give values for the plate current of a triode in which the plate and grid are both positive, correct to within about ten per cent for a wide variety of tubes and voltages. The two most important

approximations to which it is subject are (1) that secondary emission from the grid is negligible, (2) that the relation between $i_p/(i_p + i_g)$ and e_g/e_p can be represented by an exponential for any tube. Values for the constants in this equation were determined from a composite diode characteristic at low voltage and found to be accurate at much higher voltage and current. Finally it was seen that the grid current could be obtained approximately by taking the difference between this expression and that for the total space current.

This mathematical expression for positive-grid tube characteristics is extremely simple in form and sufficiently accurate for engineering purposes. It is valuable, because it avoids complicated and expensive oscillographic measurements of tube characteristics, and because it provides a new basis for attacking practical vacuum-tube problems.

Appendix A

Consider the path of a single electron which starts from some point on the cathode with negligible velocity. Its dynamical equations in rectangular co-ordinates will be

$$\frac{d^2y}{dt^2} = \frac{e}{m} E_y(x, y) \qquad (1a)$$

$$\frac{d^2x}{dt^2} = \frac{e}{m} E_x(x, y) \qquad (2a)$$

where $E_y(x, y)$ and $E_x(x, y)$ are scalar functions of the co-ordinates x and y, equal to the field intensity along the x and y axes, respectively. It is assumed that E_z is zero.

Equation (1a) may be written in the form,

$$d\left(\frac{dy}{dt}\right) = \left(\frac{e}{m}\right) E_y(x, y)\, dt \qquad (3a)$$

or

$$\left(\frac{dy}{dt}\right) d\left(\frac{dy}{dt}\right) = \left(\frac{e}{m}\right) E_y(x, y)\, dy \qquad (4a)$$

Integrating (4a)

$$\frac{1}{2}\left(\frac{dy}{dt}\right)^2 = \left(\frac{e}{m}\right) \int_{y_0}^{y} E_y(x, y)\, dy \qquad (5a)$$

Similarly from equation (2a)

$$\frac{1}{2}\left(\frac{dx}{dt}\right)^2 = \left(\frac{e}{m}\right) \int_{x_0}^{x} E_x(x, y)\, dx \qquad (6a)$$

Dividing (5a) by (6a)

$$\left(\frac{dy}{dx}\right)^2 = \frac{\int_{y_0}^{y} E_y(x, y)\, dy}{\int_{x_0}^{x} E_x(x, y)\, dx} \qquad (7a)$$

Equation (7a) is the differential equation of the path of the electron, the time element having been eliminated. Now if the grid and plate potentials are increased or decreased in the same ratio, E_y and E_x will both be increased or decreased by the same constant multiplier, which may be removed from the integral signs and divided out. Consequently, for any tube the path of a single charged particle emitted by the cathode is a function only of the ratio of electrode voltages, and not of the magnitudes.

Nomenclature

- i = current in amperes
- i_g = grid current in amperes
- i_p = plate current in amperes
- μ = constant, amplification factor
- k = constant, conductance factor
- n = constant, space-charge exponent theoretically equal to 3/2
- α = constant, distribution factor
- e_p = plate voltage
- e_g = grid voltage
- e/m = ratio of charge to mass for an electron
- E_y = y-component of electric field intensity
- E_x = x-component of electric field intensity

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Discussion

Karl Spangenberg (Stanford University, Calif.): Mr. Porter is to be commended for a clear-cut presentation of the factors involved in the positive-grid characteristics of triodes.

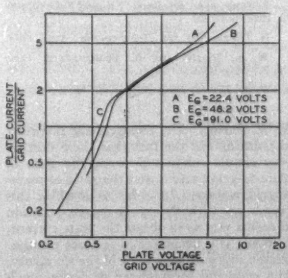

Figure 1

A limitation of the particular fundamental relationship assumed may however be indicated. The assumed relationship is of the form

$$y = e^{-ax}$$

This form permits of the selection of but one parameter in fitting the empirical formula to the observed experimental data. That is, it is only possible to fit the empirical formula to the observed data at one point. Since a choice of ordinate and curvature are not independent in the assumed form the rest of the curve may or may not fit the experimental form.

The fundamental relationship assumed by Porter for the ratio of plate to space-current leads to an admitted error of considerable magnitude in the derived expression for grid current. This may be expected from the fact that while the diversion of a fraction of the space current to the grid is a second-order effect as far as plate current is concerned, it is a first-order effect for grid current.

A possible alternative basic relation is one of the form

$$i_p/i_g = f(e_p/e_g)$$

This form was proposed by early German investigators Tank[1] and Lange.[2] They showed that the functional form was a simple power of the ratio e_p/e_g for which the exponent has very nearly the value $^1/_4$ for all tubes. The coefficient, however, varies from tube to tube. This relation has been verified by the writer for small modern transmitting tubes.[3] Essentially the same result was arrived at independently by Myers.[4] This permits the use of the basic equation

$$i_p/i_g = \delta(e_p/e_g)^n$$

which permits the selection of two parameters, the exponent and the coefficient.

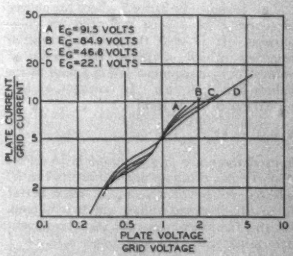

Figure 2

This form further expresses the relation in terms of the current ratio which experiences the greatest variation with voltage.

The coefficient and exponent in the above form are readily obtained by plotting i_p/i_g against e_p/e_g on log-log paper. The exponent is the slope of the straight-line characteristic obtained and the coefficient is the intercept upon the ordinate at $e_p/e_g = 1$. Such a plot is shown in figure 1. It will be observed that for values of e_p/e_g greater

than one the curves are almost coincident straight lines with about the same slope which measures to be nearly 1/3. It should be mentioned that no satisfactory theoretical explanation has as yet been given for the apparent universality of this value of the exponent in this region.

A further advantage of a plot of the type shown in figure 1 which may be mentioned is that it reveals readily any changes in the functional form which may occur in the ratio i_p/i_g. Such a change occurs in the curves of figure 1 for values of e_p/e_g of about 0.8. For values of e_p/e_g less than 0.8 the exponent as determined by the slope of the curves has a new value. The change to the new exponent occurs when the ratio e_p/e_g becomes sufficiently small so that some of the electrons which initially miss the grid are deflected strongly enough so that they are unable to reach the plate and fall back into the grid wires. For values of e_p/e_g greater than 0.8 all the electrons which initially miss the grid wires are received by the plate.

It should be pointed out that the coincidence of the curves in a plot like that of figure 1 depends upon the complete absence of secondary emission. Even the slightest traces of secondary emission will destroy the coincidence. Figure 2 shows the form of the curves for a tube with a slight amount of secondary emission. It will be observed that the curves are no longer coincident except in the vicinity of e_p/e_g where the exchange of secondary electrons between plate and grid tends to compensate. All of the curves given by Mr. Porter show considerable secondary emission by their similarity to the curves of figure 2 when plotted in that form. No satisfactory expression for current division in the presence of secondary emission has as yet been found.

It was not found possible to make the data of figure 1 fit Mr. Porter's equation because the value of α which made the curve have the proper value for $e_p/e_g = 1$ gave a curve whose curvature was much too small.

This is shown in figure 3 where the curves of figure 1 have been replotted for comparison. It is seen that the exponential function which matches the measured values for e_p/e_g equal to one is a poor fit for values less than this. If, however, an empirical curve of the form

$$y = 1 - kx^n$$

is used there are two parameters to select. A particular ordinate and curvature can be selected independently, and a much better fit to the observed values can be obtained. In this empirical formula the coefficient determines the intercept upon $e_p/e_g = 1$ and the exponent the curvature. This

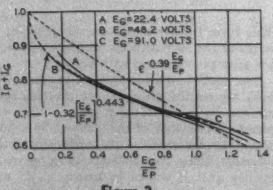

Figure 3

form permits the choice of the proper curvature from a whole family of curves with the required exponent.

Tests on and Performance of a High-Speed Multibreak 138-Kv Oil Circuit Breaker

By PHILIP SPORN
FELLOW AIEE

H. P. ST. CLAIR
MEMBER AIEE

The History and Results of High-Speed Breaker Development

HIGH-speed-oil-circuit-breaker development was really started in the period 1929–1930 and the first tests with high-speed 138-kv breakers were made at Philo in July 1930. The results of these tests, both from a breaker-design standpoint and from a system viewpoint, were described some seven years ago.[1] At that time it was definitely expected that operating benefits would be obtained out of the additional high speed but the problem of high speed was not yet then an acute or pressing one.

Parallel with that, although really anteceding that, was the development of high-speed relaying. This was first developed in what proved to be an impractical form in 1926. The original aim at that time was for a universal relay system that would operate, that is, would give an impulse to the breaker trip circuit within 20 cycles. The two developments went along in parallel although actual practical achievement in breaker speeds was attained much earlier than the relaying. However, by 1935 both achievements had been brought to such a state of perfection that it was entirely a routine matter to be able to get a six-to-eight-cycle 132-kv breaker in fairly standard construction and to get a relay system that would give universal protection in a period of one cycle or less. The history of the relay development has already been fully described.[2] By that time also the development in breakers had been carried through not only in the 138-kv classes but in the lower voltage classes as well. For special services, such as the Boulder Dam job, breakers of much faster speed were needed and three-cycle breakers of the impulse type were actually developed and built.[3]

Both of these developments have had the widest influence on the development

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1. For all numbered references, see list at end of paper.

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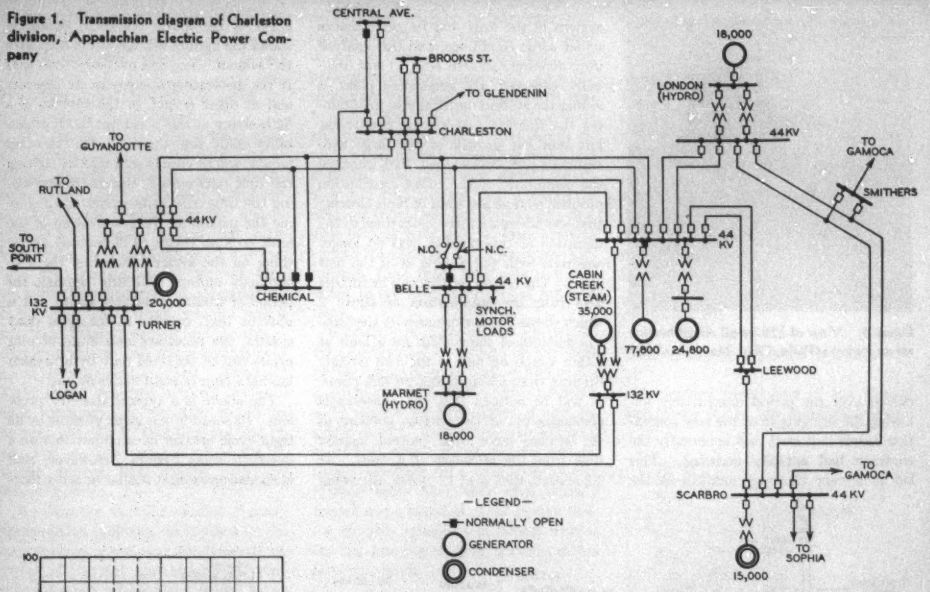
R. W. Porter: Mr. Spangenberg is correct in pointing out the fact that there exists a very simple relation between the ratio of plate-to-grid current and the ratio of plate-to-grid voltage. In order to combine this expression with the space-charge equation in such a way as to obtain the plate current, however, it is necessary to perform manipulations which destroy some of the simplicity. The empirical form shown in figure 3 will not hold for very large ratios of grid-to-plate voltage since it indicates the possibility of negative plate currents.

In general all these expressions lead to difficult integrations when applied to radio-frequency design problems, so frequently it is of great advantage to have only one parameter involving division of current between grid and plate even if the empirical curve does not match the data perfectly at all points. The chief justification for permitting a certain amount of mismatch is that under normal operating conditions most of the plate and grid current will flow when the ratio of grid-to-plate voltage is nearly one. Hence the error in design calculations can be made small even when a single parameter is used. A second consideration is that secondary emission has a tendency to increase the ratio $i_p/(i_p + i_g)$ for small values of e_p/e_g and to decrease it for high values. Consequently any spreading of the curves shown in figure 3 as a result of secondary emission will be in the direction of the exponential curve.

Figure 1. Transmission diagram of Charleston division, Appalachian Electric Power Company



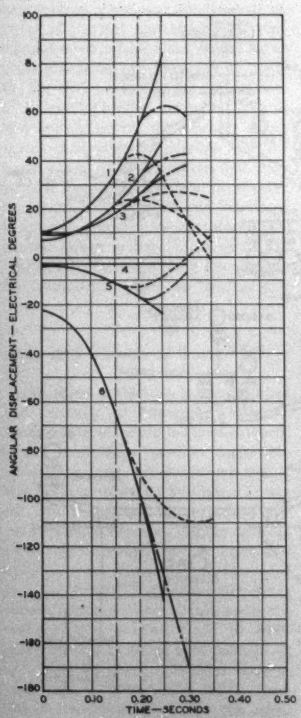


Figure 2. Swing curves from stability study of Charleston division

and successful performance of modern transmission lines and networks. The effect on electric-power-system development and operation of these developments in breakers and relays can best be illustrated by a few typical examples of problems arising in transmission system operation and performance where the solution from a practical standpoint can be obtained only by a faster clearing of faults, which in turn can be obtained only by a high-speed breaker and in many cases only by a high-speed breaker coupled with a fast relay system.

Figure 1 shows a portion of the transmission system of the Appalachian Electric Power Company which operates in Virginia and West Virginia. This transmission system also extends to the affiliated companies, the Kentucky and West Virginia Power Company, Incorporated, and Kingsport Utilities, Incorporated, operating in Kentucky and Tennessee, respectively. The portion that is of particular interest is that part of the Charleston division lying between the Turner substation, which is west of Charleston, W. Va., and the Cabin Creek plant located at Cabin Creek Junction, W. Va., which is the principal steam plant serving that region and the immediately surrounding area. The loads in this territory are comparatively heavy, being predominantly coal and chemical operations. At the Belle substation, some six miles from Cabin Creek, a single load which some eight or nine years ago started at about 3,000 kw has now increased to approximately 42,000 kw, the principal use of power being in the operation of synchronous motors as large as 2,700 horsepower which drive high-pressure (1,200-atmosphere) compressors. Although some difficulty was experienced with surges in the early days when this load was building up, the problem seemed to have been entirely cleared up after an extensive investigation was carried out some five years ago, which showed the desirability of making some control changes on the motors and speeding up of the breakers on all the lines in the immediate neighborhood of the load.

About 2½ years ago an additional source of generation was brought in almost directly on the bus bar of the main substation supplying this load. It was expected that this would have a beneficial effect on the stability of the supply system, but a series of disturbances that oc-

1—London
2—Marmet
3—Cabin Creek
4—Turner 132-kv system
5—Scarbro condenser
6—Belle motor load
——— Fault on
– – – Fault cleared by simultaneous opening of breakers in 0.20 second = 12 cycles
– · – · Fault cleared by simultaneous opening of breakers in 0.15 second = 9 cycles

Figure 3. View of 138-kv oil circuit breaker set up for test at Philo, Ohio, November 1937

curred over the period immediately following the bringing in of the new generation source indicated that apparently the contrary had actually occurred. This led to a very thorough analysis of the system in the area and its performance under surge conditions, and this analysis very definitely showed that as was originally expected, the generating plant is aiding the system materially in maintaining the stability and voltage conditions, but that the growth of the large synchronous-compressor load had changed the complexity of the entire distribution problem so that a system of fault clearing that was adequate three years prior to the initiation of this trouble, was no longer adequate with the coming in of the new plant. The reason for this can be further seen from an examination of figure 2 which shows the performance of the various portions of the system for a fault at Cabin Creek on one of the two circuits running from Cabin Creek to this point. It will be noticed that the phase-angle displacements of the various portions of the system have been plotted against time from the initiation of a fault. At 0.2 second, that is at 12 cycles, the swing curve of the motor (curve 6) definitely shows the motors will fall out of step with the system. The rest of the system, that is the generating equipment at Marmet and at other points on the system, is a little shaky at this point but in all probability could ride through. On the other hand it will be clearly seen that by cutting the time 0.05 second, that is by decreasing the time only three cycles and reducing the maximum time of clearing of the fault to nine cycles (0.15 second) everything on the system, including the synchronous motors, will ride through the period of trouble in perfect safety. It is obvious that, granted a one-cycle relay system, the necessary maximum of nine cycles can be obtained only by a breaker having a time of eight cycles or less.

The above is a typical stability problem. Its solution was made possible by an eight-cycle breaker in combination with a one-cycle relay system. However, that is no guarantee that similar or other more

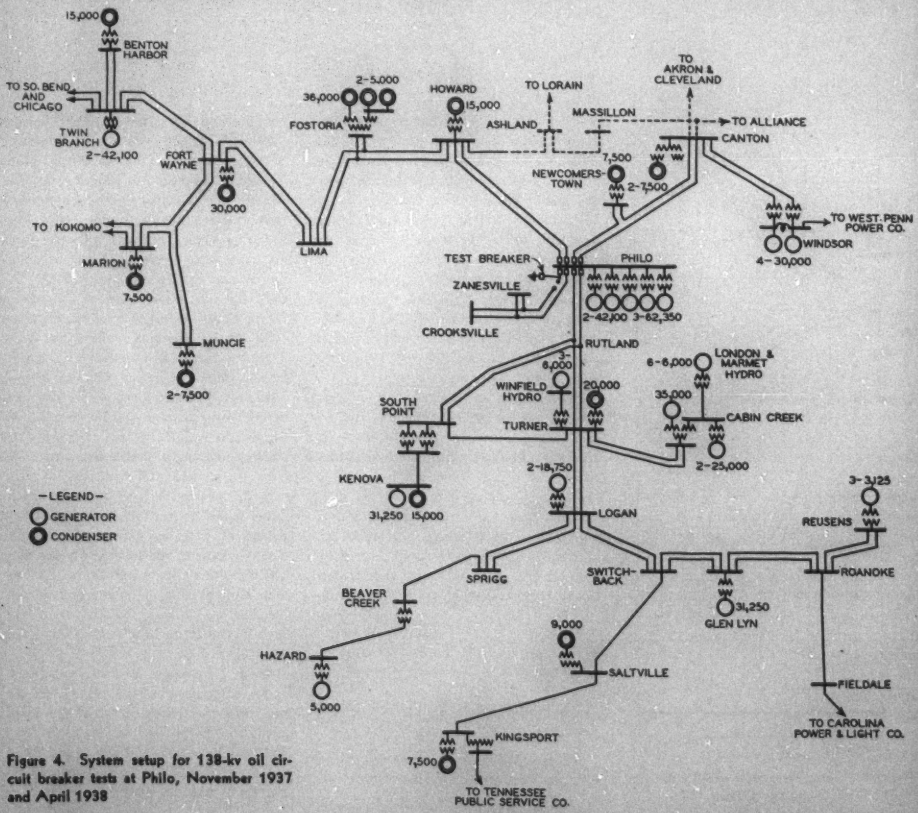


Figure 4. System setup for 138-kv oil circuit breaker tests at Philo, November 1937 and April 1938

involved problems in the future will not call for even faster time. If it is granted that one-cycle relay time is about as fast as can practically be sought, it is obvious that more breaker speed and speed beyond eight cycles is needed.

As a matter of fact such a need arose in connection with the development of ultrahigh-speed reclosing of transmission lines.[4] Here, although ultrahigh-speed reclosing was successfully accomplished on a breaker having very little better time than eight cycles, it was evident that the amount of waiting time with the line de-energized, necessary to bring about deionization, was not only a function of the arc current and the atmospheric conditions, but was also dependent upon the duration of arcing. Obviously if the arcing time was reduced, the total time necessary for reclosure would be reduced not only by that time but also by the additional gain as a result of the reduced waiting time needed with line de-energization.

A realization that the solution of many transmission problems, as typified by the two outlined above, was possible only by virtue of the fact that high-speed interruption was available when needed led to a decision some two years ago to apply the knowledge gained in the development of the impulse breaker to the development of a breaker having substantially higher speeds than appeared possible with the conventional oil blast breaker, and to do so along lines that would give the breaker no insurmountable economic handicaps in finding application on normal and commercial power systems. The results of that development are being described in the companion paper of Spurck and Strang.

Aims and Objects of Tests

The object of the tests herein described was basically to determine whether a breaker designed along the lines outlined[5] would successfully perform under the severe duty and test conditions that it was possible to set up at Philo. It was felt that in the light of the broad background of experience on breaker developments and tests obtained over a period of some 12 years, it was not safe to assume that the design difficulties encountered in making a change such as is invo ved in the development described could be overcome without thorough field testing. It was felt that these difficulties were so great that even with the fullest theoretical background and with the maximum amount possible in factory testing, it was not reasonable to expect even the most skilled designer to take care with finality of all the problems that were bound to arise. Hence the only safe basis of procedure, particularly since the equipment was protective equipment, was to subject the design to severe field tests and thus bring to light initial design errors and weaknesses. Past experience had indicated that those were almost inevitable and that designs put through the finishing developmental stages made possible by such tests were far more likely to operate trouble-free and completely successfully than those that were not subjected to the rigid experience of full field tests.

In short, it was hoped through this development and these tests to get a breaker having a time possibly close to four cycles in a design sufficiently simple, however, as to involve no appreciable, if any, increase in cost. Past experience had indicated that with a growing power system, having available such designs on an economical basis when they were actually needed was a material factor in maintaining not only reliability of system service, but in keeping system growth within economic limits.

System Setup for Tests

The Philo plant on the system of The Ohio Power Company provides the greatest concentration of power on the American Gas and Electric Company 132-kv system and was, therefore, chosen again, as in 1930, as the best place to test the new oil circuit breaker. As a matter of fact, the test breaker was set up in almost the same location with respect to the 132-kv switchyard as in 1930,[1] and it was connected in the same way to the transfer bus so as to make use of one of the Crooksville oil circuit breakers as a back-up breaker. A view of the breaker setup for test is shown in figure 3.

Likewise, the system setup as shown in figure 4 did not differ materially from that available for the 1930 tests, although a number of important system changes have been made since then. These include the double circuiting of the line from Philo all the way to Twin Branch, the installation of a 36,000-kva synchronous condenser at Fostoria, the placing in service of the hydro plants at London, Marmet, and Winfield, and the erection of a new 132-kv line from Turner to South Point. Except for the Howard line, which contributed substantially more current to the short circuit because of double circuiting, the effect of these changes in system setup and generation made very little difference in the short-circuit current contributions from these lines for a short circuit at Philo. At the Philo plant although the electrical end of the plant itself is exactly the same as in 1930, the actual short-circuit current supplied by the generators, as well as the total short-circuit current, was substantially greater due to the increased mechanical speed of the breaker and the consequent smaller decrement occurring prior to parting of the breaker contacts. This factor, together with the increase in system capacity mentioned above, made it possible to record tests as high as 2,000,000 kva based upon the initial current in the arc.

Description of the New Breaker

A detailed description of the design and theory of the new multibreak inter-

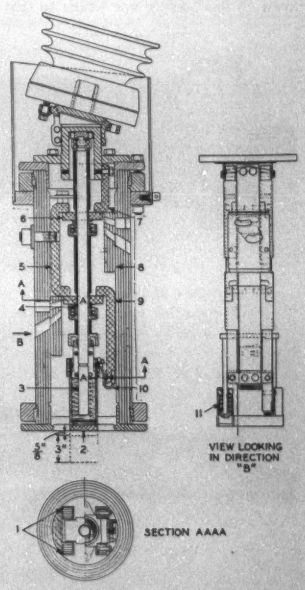


Figure 5. Cross section of multibreak, high-speed interrupter used in oil circuit breaker tested at Philo, April 24, 1938

1—Contact support rods
2—Contact cap
3—Springs
4—Contact pressure springs
5—Stationary contact bar
6—Movable contact
7—Stationary contact bar
8—Port segment
9—Stationary contact bar
10—Flexible connection
11—Opening springs

rupter, with particular reference to the six-break, 230-kv type, is given in the Spurck and Strang paper. The interrupters used in the test breakers at Philo were, of course, of the four-break design and were installed in a 138-kv conventional type of oil circuit breaker using standard 60-inch round tanks as shown in figure 3. A cross section of the interrupter itself is shown in figure 5, and a photograph of the interior parts alongside of the enclosing cylinder is shown in figure 6. The latter shows the general appearance of the interrupter, including the double-port opening in the side of the enclosing shell, whereas the cross section (figure 5) shows the arrangement of the four breaks, current carrying parts, location of port openings with respect to the interrupting breaks, and the compression springs along the central insulating rod.

The high-speed operating mechanism used on this breaker was similar to that shown schematically in figure 4 of the Spurck and Strang paper, except that it was designed for ultrahigh-speed reclosing, although most of the parts necessary for reclosing service were omitted. As shown in figure 3, this mechanism was mounted on the end of number 1 tank of the breaker.

Test Program and Results

Three series of tests, the first on November 20 and 21, 1937, the second on November 28, 1937, and the third and final series on April 24, 1938, were carried out on this breaker. This program may be summarized briefly as follows:

(*a*). Interrupters of the single-port design as described by Spurck and Strang were used in the first series of tests but failed to withstand the internal pressures developed in connection with currents somewhat above their rating.

(*b*). In the second series of tests, using two poles only, one pole was equipped with single-port interrupters, while the second pole was equipped with double-port interrupters and larger total port area. As in the previous tests, the single-port interrupters failed to withstand the pressures developed at currents somewhat above their ratings, whereas the double-port interrupters performed successfully and the series of tests was completed on a single-phase basis.

(*c*). The third and final series of tests was carried out on a complete three-phase basis, using interrupters with double-port openings and substantially strengthened enclosing cylinders, together with other minor modifications. The breaker came through these tests in a completely successful manner.

Detailed results of these tests are given in tables I, II, and III covering the first, second, and third series of tests, respectively. These results will be described in more detail below:

Tests of November 20 and 21, 1937

As shown in table I, six preliminary tests were made, using one generator only, the first test primarily to check the test setup, and the other five with varying excitations on the generator to furnish information in connection with generator reactance characteristics. The remainder of the tests on November 20, included, first, a series of eight shots with two

Figure 6. View of interior parts and enclosing cylinder of interrupter after tests at Philo, April 24, 1938

Figure 7. Oscillogram of test number 7, November 20, 1937, showing interruption of 1,500 amperes in 3.5 cycles

Figure 8. Oscillogram of test number 38, November 28, 1937, showing interruption of 8,500 amperes, single phase, in 3.7 cycles

Table I. First Series of Tests—November 20 and 21, 1937

Test Number	Type	Machines at Philo (Kva)	Lines Connected to 132-Kv Bus	Initial Current in Arc			Breaker Time (Cycles)			Equivalent Kva Interrupted	Remarks
				1	2	3	1	2	3		
1	O	1 42,100	None	1,000	940	990	Delayed	tripping		230,000	Tests for generator reactance data
1A	O	1 42,100	None				Delayed	tripping			
2	O	1 42,100	None	92	92	92	Delayed	tripping		6,400	0.25 normal voltage
3	O	1 42,100	None	170	170	170	Delayed	tripping		21,000	0.50 normal voltage
4	O	1 42,100	None	240	240	240	Delayed	tripping		42,000	0.75 normal voltage
5	CO	1 42,100	None				Delayed	tripping			1.00 normal voltage
6	O	1 42,100	None				Delayed	tripping			1.10 normal voltage
7	O	2 42,100	None	1,500	1,400	1,200	3.7	3.5	3.4	360,000	Cleared OK
8	O	2 42,100	None	1,500	1,300	1,400	3.8	4.1	3.4	360,000	Cleared OK
9	CO	2 42,100	None	1,400	1,500	1,500	4.1	4.0	3.9	360,000	Cleared OK
10	CO	2 42,100	None	1,450	1,200	1,600	4.6	4.4	4.2	380,000	Cleared OK
11	O	2 42,100	1—Canton line open at far end	1,600	1,450	1,200	3.0	3.5	3.8	380,000	Cleared OK
12	O	2 42,100		1,200	1,400	1,600	4.2	3.6	3.4	380,000	Cleared OK
13	CO	2 42,100		1,300	1,350	1,350	4.3	3.7	3.9	320,000	Cleared OK
14	CO	2 42,100		1,200	1,400	1,300	4.3	3.7	4.0	335,000	Cleared OK
15	O	1 187,000	2—Howard, 2—Rutland closed to system	4,200	3,900	4,700	3.9	3.3	4.2	1,100,000	Cleared OK
16	O	1 187,000		4,300	4,300	4,200	4.2	3.6	3.9	1,000,000	Cleared OK
17	CO	1 187,000		4,500	4,000	5,300	3.1	2.5	1.5	1,270,000	Cleared OK {Poor contact number 1 pole}
18	CO	1 187,000		4,000	4,800	3,800	3.0	1.4	2.7	1,150,000	Cleared OK
19	O	1 187,000	All except Crooksville	6,500	6,700	6,350	3.5	3.4	3.8	1,600,000	Cleared OK {Poor contact number 1 pole}
20	O	1 42,100		6,800	6,700	6,300	3.6	3.5	3.3	1,620,000	Cleared OK
21	CO			5,900	7,800	6,600	6.0	0.5	0.3	1,860,000	Cleared OK. Heavy jar, poor contact number 1 and number 3 poles
22	CO	1 187,000 1 42,100	All except Crooksville	0	5,800	6,400		3.5	3.4	1,530,000	Cleared OK. No current number 1 pole. Poor contact number 3 pole Interrupter number 1 pole shattered on test number 21
23		1 187,000	All	0	0	8,000			3.6	1,900,000	Cleared OK. Tests number 3 pole only
24		2 42,100	All	0	0	7,600			3.2	1,820,000	Cleared OK
25			All	0	0	7,300			3.3	1,750,000	Cleared OK. Heavy jar. Interrupter number 3 pole shattered

generators only, including four tests with and four without a transmission line connected to the 132-kv bus to furnish a comparison between high- and low-voltage recovery rates. While the longest breaker time occurred with the high recovery rate setup where no lines were connected, the average results showed no consistent difference. This comparison, of course, was not particularly satisfactory because of the relatively low short-circuit current involved. It was not feasible to make such a comparison at higher levels of short-circuit current. All of these tests, 1 to 14, inclusive, in table I, were made on a setup completely isolated from the rest of the system.

Tests 15 to 18, inclusive, at a duty slightly above 1,000,000 kva, were carried out on November 21 without incident, with breaker time from less than two cycles to slightly over four cycles. On the next four shots, tests 19 to 22, inclusive, with slightly less than the full system capacity, the first two were entirely successful at approximately 1,600,000 kva, whereas test number 21 showed evidence of distress, and on test number 22 no current was obtained in phase 1 as a result of the complete shattering of one of the interrupters in that phase on the previous test. Three more shots were then carried out on a single-pole basis, the last of which at 1,750,000 kva destroyed one of the remaining interrupters, thus concluding the first series of tests.

Figure 7 shows an oscillogram of test number 7, a typical light shot of this series. The points at which tripping, contact parting, and interruption occurred and the actual breaker time are indicated on the oscillogram.

Tests of November 28, 1937

Between November 21 and November 28, two sets of interrupters sufficient to equip two breaker poles were reconstructed one with single-port openings approximately the same as on the initial tests, and the other with double-port openings and increased port area. As shown in table II, the interrupters with a single port, after withstanding four shots at light duty and two shots slightly above the full rating, failed on test number 32, causing mechanical damage to the interrupter and allowing arcing in that pole to continue for something more than thirty cycles until the back-up breaker opened the circuit. Subsequent examination of the interrupters in pole 2 indicated that electrical arc-over as well as mechanical damage had occurred.

Single-phase tests were then continued on the single pole with the double-port interrupters, concluding successfully a series of six with the full system capacity and a maximum recorded value of 2,000,000 kva on the last two shots. An oscillogram showing one of these last two heavy shots, test number 38, is presented in figure 8. As noted on the oscillogram, the opening time of the breaker in this case was 3.7 cycles.

Tests of April 24, 1938

While the series of single-phase tests on the double-port interrupters as completed on November 28, 1937, was entirely successful, nevertheless it was felt that, as a definite proof of the final design, it would be advisable to carry out a series of three-phase tests on the breaker equipped throughout with the double-port interrupters. This was particularly so since in the final interrupters, the designers, taking advantage of the information gained from previous tests, had made a number of modifications, such as increased strength of enclosing cylinders, improved electrical insulation, and other changes of a minor character.

The results of this final series of tests are shown in table III. These show that the breaker in its final form gave a most creditable performance. As shown in this table, after two preliminary shots with two generators only, the breaker was subjected immediately to four tests at duties between 1,400,000 and 1,500,000 kva, followed by six shots at the full system capacity, with a maximum of about 2,000,000 kva. As shown also in table III, on the last ten shots which were taken at duties from 1,400,000 to 2,000,-

Table II. Second Series of Tests—November 28, 1937

Test Number	Type	Machines at Philo (Kva)	Lines Connected to 132-Kv Bus	Initial Current in Arc 1	Initial Current in Arc 2	Initial Current in Arc 3	Breaker Time (Cycles) 1	Breaker Time (Cycles) 2	Breaker Time (Cycles) 3	Equivalent Kva Interrupted	Remarks
26	O	2 42,100	None	This pole not connected	1,800	2,000	3.7	4.0		480,000	Cleared OK
27	O	2 42,100	None		1,850	1,600	3.6	3.3		440,000	Cleared OK
28	CO	2 42,100	None		1,900	1,850	3.8	5.0		450,000	Cleared OK
29	CO	2 42,100	None		1,600	1,900	4.0	4.7		450,000	Cleared OK
30	O	1 187,000	All except Crooksville	This pole not connected	6,700	6,300	3.5	3.3		1,600,000	Cleared OK [pole 3
31	O	1 42,100			6,500		3.3			1,550,000	Cleared OK. No oscillogram
32	CO				6,200	6,900		3.3		1,650,000	Arced to end of stroke on pole 2. Sustained oil spray from tank 2. Cleared by back-up breaker. Interrupters in pole 2 damaged
33	O	1 187,000	All except Crooksville	Poles 1 and 2 disconnected	5,900		3.3			1,400,000	Cleared OK Pole 3 only with doubleport interrupters on remainder of tests
34	CO	1 42,100			6,000		3.5			1,430,000	Cleared OK
35	O	1 187,000	All	Poles 1 and 2 disconnected	8,200		3.5			1,960,000	Cleared OK Added solid neutral ground to 2–63,000 kva banks not previously grounded. All other banks grounded throughout.
36	CO	2 42,100			7,700		3.9			1,840,000	Cleared OK
37	O				8,500		3.3			2,000,000	Cleared OK
38	CO				8,500		3.7			2,000,000	Cleared OK

000 kva, the breaker time varied from the maximum of 3.5 cycles to a minimum of less than two cycles. On the first two shots, however, which were made at light duty and, incidentally, at a high recovery rate, the breaker time, as would be expected, is somewhat longer. On shot number 2 this time reached a maximum of 5.7 cycles on pole number 2, which interrupted 1,400 amperes or the equivalent of 335,000 kva. Inasmuch as the duty in this case was actually less than 25 per cent of the breaker rating, the five-cycle speed rating of the breaker was, therefore, not actually exceeded under the prevailing standard rules for breaker rating. A typical oscillogram taken during this series of tests, showing the interruption on test number 8, is reproduced in figure 9.

The entire series of tests was carried out without any indication of distress, the only outward evidence of circuit interruption being the noticeable jar transmitted through the cinder-filled ground occupied by the test setup and a small amount of smoke or vapor issuing from the vent pipes on the tanks.

Following the tests, all of the interrupters were removed from the tanks for inspection and were found to be in excellent condition, showing no signs of distress whatever. A photograph of one of the interrupters taken after the completion of the tests is shown in figure 6. This is typical of all of the interrupters removed from this breaker. With the small amount of burning indicated on the contacts, it appeared that the interrupters could have withstood many more tests without maintenance or adjustment.

As would be expected, oil samples taken immediately after the tests showed no noticeable discoloration and tested an average of 30 kv, the same as at the beginning of the tests.

Effects of Tests on System Operation

In order to minimize the possibility of disturbances to customers during these tests, special arrangements were made to take care of certain areas electrically close to the Philo bus and thereby subject to the greatest voltage dips. The Newark area was taken care of by operating the Newark steam plant, tied in with the system only through a 66-kv line extending north to Howard substation and entirely disconnected from the normal 132-kv source at Crooksville. On the other hand, the town of Zanesville, which included among its factories a number of glass plants, which are generally particularly susceptible to voltage dips, had to be subjected to the full disturbance, as there was no other way to supply the town. Therefore, as a precautionary measure, the large industrial customers were notified as to the exact time of carrying out the shots with full system capacity in order that they could have operating men on hand to restart any motors which might possibly drop out because of some unforeseen contingency or because of, perhaps, some instantaneous under-voltage releases.

Except for these precautions, the effect of the tests on the system may be said to have been practically negligible as far as any harmful effects are concerned.

Conclusions

This entire program of field tests in connection with the development of this new high-speed interrupter has again demonstrated what was brought out in the beginning of this paper, namely, that no matter how skilled the designers may be, and with the most exhaustive research testing that is possible in factory testing laboratories, it is still necessary to look

Figure 9. Oscillogram of test number 8, April 24, 1938, showing interruption of 7,700 amperes in 3.25 cycles

Table III. Third Series of Tests—April 24, 1938

Test Number	Type	Machines at Philo (Kva)	Lines Connected to 132-Kv Bus	Initial Current in Arc 1	Initial Current in Arc 2	Initial Current in Arc 3	Breaker Time (Cycles) 1	Breaker Time (Cycles) 2	Breaker Time (Cycles) 3	Equivalent Kva Interrupted	Remarks
1	O	2 42,100	None	1,600	1,400	1,500	3.6	3.6	3.7	380,000	Cleared OK
2	CO	2 42,100	None	1,600	1,400	1,300	4.2	5.8	5.0	380,000	Cleared OK
3	O	1 187,000		5,700	5,700	6,500	3.2	3.0	3.3	1,550,000	Cleared OK
4	O	1 187,000	All except Crooksville	6,000			3.5			1,430,000	Cleared OK. No record poles 2 and 3
5	CO	1 187,000		5,700	5,700	5,800	3.4	3.2	2.6	1,380,000	Cleared OK
6	CO	1 187,000		5,900	5,600	5,800	3.5	3.3	3.2	1,400,000	Cleared OK
7	O	1 187,000	All	6,700	7,100	7,400	2.9	3.2	3.0	1,760,000	Cleared OK
8	O	2 42,100	All	6,800	7,100	7,700	2.9	3.3	3.1	1,840,000	Cleared OK
9	CO	2 42,100	All	8,200	7,500	7,300	3.2	1.5	1.3	1,960,000	Cleared OK
10	CO	1 187,000	All	8,200	7,300	7,200	2.7	1.7	1.4	1,960,000	Cleared OK
11	CO	2 42,100	All	7,000	7,300	7,700	3.5	1.3	1.6	1,840,000	Cleared OK
12	CO	2 42,100	All	7,500	8,500	8,500	3.4	2.7	1.6	2,000,000	Cleared OK

to actual high-capacity field tests for ultimate confirmation of circuit breaker designs and to bring out possible weaknesses which otherwise may escape disclosure. In this particular development there is no question but that the fundamental design of the interrupter and, in general, its details had been worked out on a sound basis. It is no reflection whatever on the designers that unforeseen weaknesses were disclosed in the tests; on the contrary, it is proof of the soundness of the development that comparatively minor changes based upon the information obtained from the tests were all that were necessary to enable the final design to go through what is believed to be the most severe series of tests yet made on a high-voltage circuit breaker and do so with perfect performance.

It is also interesting to look at this development in the light of what has recently been said and written in considerable volume on the subject of oilless and oil-poor circuit breakers. A great deal of development work, largely abroad, but in an appreciable amount also in this country, has been going on in this field and many engineers have felt that such oilless or oil-poor breakers might eventually become the final answer to the circuit-breaker problem. Here we have, however, in an oil circuit breaker of the conventional type, the culmination of developments which have been carried along for some years in an orderly manner, resulting in a breaker which, with a rating of 1,500,000 kva, has demonstrated its ability to interrupt repeatedly and with no apparent effort, short circuits at and well above its rating, up to maximum values of 2,000,000 kva, with speeds consistently under four cycles. Viewed from this angle, we cannot help but feel that this development is truly a tribute to the level-headed skill and ingenuity of our American designers.

It goes without saying that the carrying out of tests of this nature represents not only an actual expense in time, construction, and even fuel cost, but also a considerable amount of stress and disturbance to the personnel operating a large power system. For all of this, however, we feel that we have been well repaid, first, because of the added confidence in the ability of the equipment and the system as a whole to handle disturbances smoothly gained by the operating forces and, second, for having been of assistance in putting the final necessary touches on a development which is without doubt a notable one, and one which will become of considerable value both now and in the future as a much needed tool in the development, expansion, and safe operation of large inter-connected power systems.

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Discussion

J. B. MacNeill: See discussion, page 710.

W. F. Sims: See discussion, page 711.

S. B. Crary (General Electric Company, Schenectady, N. Y.): Power-system stability has been an important factor in determining the maximum allowable fault-clearing times. If we consider generator stability only and not load stability, total fault clearing times of the order of nine cycles for complete clearing of the fault appear to be adequate for even the most severe faults on the majority of power systems. Exceptions exist, of course, when the transmission distances are great and the steady-state power margins correspondingly low. However, fault-clearing times less than that calculated as the maximum allowable for generator stability are desirable in that a margin of safety is obtained which allows for unforseen extreme loadings and operation. Also the lower the switch time the greater the time or flexibility which can be allowed for relaying. In some cases this will allow for sequential switching out of the faulty section rather than requiring simultaneous switching.

The paper by Messrs. Sporn and St. Clair discusses a problem which it is believed will become of increasing importance. This is the ability to remove severe faults quickly enough so that important synchronous motor loads will not be lost. A synchronous motor is particularly liable to loss of synchronism for the following reasons.

1. When the fault is on, the synchronous motor tends to decelerate due to its shaft load and the losses due to the flow of fault current. This is not the case for a generator as the losses due to the flow of fault current decrease the acceleration and therefore are beneficial.

2. The size of the individual synchronous motors is usually small, so that the field flux decays more rapidly than in a generator due to the armature reaction created by the flow of fault current and the swing or oscillation after the fault is cleared.

3. The per-unit effective inertia of the rotating element is usually much less than that of generators. Exceptions exist, of course, for the case of high-inertia loads. This means that the angular displacement, in general, increases more rapidly.

4. Synchronous motors are not usually provided with voltage regulators. This combined with the low field time constant, reduces their synchronous strength appreciably during the period the fault is on and immediately after it is cleared.

5. Operators of industrial plants are not always cognizant of the stability problem or the importance of it, so they are apt to purchase and install motors which do not necessarily have high pull-out torques. A large group of motors of only ordinary characteristics or a motor connected through a long line to a system may have very little stability margin even under steady-state conditions.

All these factors combine to make the synchronous-motor load particularly susceptible to pulling out of step. A most effective manner to prevent their losing synchronism is by quick switching. Because of the nature of synchronous motor loads, the fault-clearing times for severe faults and locations relative to the syn-

chronous motor load must be quicker than that required in general for corresponding severe faults relative to the generating station. Fault clearing times of less than nine cycles then become highly desirable.

If a power system has connected to it important synchronous-motor loads which require a high degree of service, then the need for very quick switching will undoubtedly exist for severe faults relative to the synchronous motor load.

L. F. Hunt (Southern California Edison Company, Ltd., Los Angeles, Calif.): The authors should be commended for their paper, and they should receive congratulations for their courage in pioneering actual system oil-circuit-breaker-short-circuit tests. The work involved in lining up a system for short-circuit tests is enormous, and the reading of a paper such as this really does not give the reader a full understanding of the intricacy of such tests.

The engineers of the Southern California Edison Company, Limited, agree with the authors that the final proving ground for oil switches is the actual system short-circuit tests. In fact, the latest policy has been to make system tests on breakers to ascertain complete information of their operation.

If I may digress from the paper a small amount, I would like to mention that we have conducted many tests on switches, and more recently have conducted about five series of tests on 230-kv breakers on our 220-kv system. Two series of tests were made on 230-kv breakers in accordance with the ones discussed in the paper, except having six breaks per pole instead of four. The first series was on April 25, 1937. The results of these tests read like a carbon copy of the authors' first series of tests November 20 and 21, 1937, except we were more fortunate in that we did not require the operation of a back-up breaker. Then on October 17, 1937, we ran the second series of tests with a much improved mechanical designed interrupter described in the Spurk and Strang paper. These tests also were successful, as in the case of the authors' third series of tests. You will note that our final tests were made prior to the authors' first test.

Just one question occurs to me. In the case of a failure on the test switch, how sure are you that the back-up breaker will take the rap and clear successfully?

Again, I wish to congratulate the authors and their men for the courage of these and other tests. The valuable information gained will give all switch users better switches.

D. C. Prince (General Electric Company, Philadelphia, Pa.): It seems appropriate to comment at this time on the debt of gratitude which switchgear manufacturers owe to operating engineers like Mr. Sporn, who have the courage and willingness to subject their systems to high-power field testing. A high-power test laboratory is a very expensive thing. The largest laboratories in this country have a symmetrical capacity a little over 500,000 kva and can deliver about 1,000,000 kva with a full offset wave. This is small compared with a 2,500,000-kva-rated breaker.

Various methods are employed to substantiate ratings beyond test plant capacity. These include pretripping, two-part tests, and other special arrangements. While there is good reason for having confidence in the data obtained from such tests, yet we all like to see how a circuit breaker behaves when it clears a fault on an actual system of large capacity.

Without field tests a new design may operate for months or years before its quality is tried by a real fault. The 287-kv transmission lines from Boulder to Los Angeles were so carefully protected by ground wires and counterpoises, and so well built that the circuit breakers were not called into automatic operation for nearly a year and a half. Then the flood came and there was a washout on both lines and the circuit breakers isolated the faulted sections with hardly a blink of the lights. When the actual emergency arose of course there was no oscillographic equipment hooked up so that no one knows what actually did happen.

The great power concentration around Philo actually delivered 2,000,000 kva to a fault which was cleared by the test breaker with all important events measured. Due to Mr. Sporn's courage and thirst for facts, we have an assurance of protection under actual operating conditions even though these conditions may include a catastrophe of nature such as the flood which damaged Boulder Dam–Los Angeles lines.

V. M. Marquis (American Gas and Electric Service Corporation, New York, N. Y.): A great many of us believe that the oil circuit breaker as an interrupting device represents a notable engineering achievement. To forcefully bring this out, it would be interesting to compare its performance with that of other methods of stopping the flow of energy, such as, for example, with a high-pressure valve, a brake, or a fire extinguisher. However, to make a comparison between the oil circuit breaker and other devices or mechanisms for interrupting the flow of energy is rather difficult. In the case of the oil circuit breaker, the actual energy in the arc is low, perhaps not more than 1,000 kilowatt-seconds. The power factor of the faulted circuit is probably ten per cent or less. Furthermore, the circuit breaker resorts to the trick of interrupting the arc when the current passes through zero. Granting all of this, it must be remembered that when the circuit breaker is attempting to extinguish the arc, the system voltage (in this case 132,000 volts) is at all times attempting to recover and although the current is interrupted when it passes through zero, it must be further borne in mind that the three phases do not open simultaneously, and therefore instantaneously there is an interchange of single-phase power (the mean of which is zero) between the phases which in kilowatts may possibly be equal to the kilovolt-amperes interrupted. All of this results in heavy forces which the oil circuit breaker must withstand because of the magnetic field and the making of room for the gas bubbles as fast as they are formed.

A comparison, although perhaps rather crude, might be made between the oil circuit breaker and the latest devices for extinguishing oil fires. We have made a rough comparison on this basis with some recent tests in which large oil fires were extinguished by means of water from high-pressure nozzles. The calculated equivalent of mechanical power represented by the fires in these tests, based on burning ten gallons of oil per minute, is approximately 25,000 kw, and the best performance obtained in putting out these fires was approximately 20 seconds. On this basis it is obvious that the circuit breaker compares most favorably in doing its job in three cycles or $^1/_{400}$ of the time taken to extinguish the fire.

This breaker is reported to have interrupted a 2,000,000-kva short circuit in approximately three cycles, and as shown by the film, a puff of smoke from the vents was the only visible sign that anything had happened. It may be of interest to compare this with the oil fire by showing a short section of film of the oil fire tests already referred to. Regardless of the accuracy of the comparison, I think we can all agree that the modern oil circuit breaker performs efficiently a most difficult job in an extremely short period of time.

Philip Sporn and H. P. St. Clair: In closing the discussion on this paper, the authors would like, first of all, to thank those who have contributed some very interesting and helpful discussions. It is particularly gratifying to find that these contributors have shown by their discussions, as well as by direct expression, that they fully appreciate the scope and importance of an undertaking such as that described.

Mr. Crary, we believe, has brought out the importance of high-speed switching in connection with the problem of stability involving synchronous-motor loads. We have already included in the paper some discussion of one such problem which was actually solved by speeding up circuit-breaker operation and we might say that there are many synchronous motor applications on almost any system which will, in general, be affected by the speed of switching. This problem, in fact, we consider to be one of the major arguments in favor of high-speed switching.

Mr. Sims shows a keen appreciation of the development work which has been done both by the manufacturers on this breaker and by our company in bringing this to a successful conclusion by means of test. In pointing out that the design of the new interrupter is such that it may be applied to replace corresponding parts of older breakers at a very great saving over the complete replacement of breakers, Mr. Sims has emphasized again the credit which we have given in the paper to our American designers for the progress they have made in improving the conventional oil circuit breaker along conventional lines.

We are very glad indeed to note from Mr. Hunt's discussion that the engineers of the Southern California Company, Limited, have arrived at the conclusion that the only reliable final proving ground for oil circuit breakers is actual short-circuit tests and that it is the policy of the company at the present time to make such tests on the system. As we have stated many times before, we are firmly convinced of the soundness of this position and we fully expect to continue making system short circuit tests whenever it is necessary to prove out a new

A New Multibreak Interrupter for Fast-Clearing Oil Circuit Breakers

By R. M. SPURCK
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H. E. STRANG
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Synopsis: A description of a new multibreak interrupter for fast clearing of short circuits applicable to high-voltage conventional tank-type oil circuit breakers. Breakers equipped with such interrupters were subjected to interrupting tests on large 138-kv and 230-kv systems during which short circuits as high as 2,000,000 kva were interrupted in less than five cycles. The results of those interrupting tests are shown and discussed.

IT IS generally recognized that fast clearing of short circuits on power systems is desirable because among other benefits, shortening the duration of short circuits reduces the:

(*a*) Tendency of the system to become unstable.

(*b*) Magnitude and duration of voltage dips.

(*c*) Burning of the conductors at the point of short circuit.

(*d*) Potential damage to apparatus.

As the breaker interrupting time, that is, the time measured from the instant the trip coil is energized until the short circuit is interrupted, is an important part of the time required to clear a short circuit, much attention has recently been given to the development of breakers having short interrupting times. Most breakers sold today for all voltages and interrupting ratings, have a rated interrupting time of eight cycles, 0.133 second. Some few breakers for special applications have had interrupting time ratings of three cycles, 0.05 second. Breakers of that time rating, utilizing the impulse oil-blast principle in which oil is forced between the contacts by a mechanically driven piston, are used on the 287.5-kv transmission line between Boulder Dam and Los Angeles[1] and on the 138-kv side of the autotransformers of the Los Angeles end of that line. Also, many single-phase impulse oil-blast-type breakers having an interrupting time of one cycle, 0.04 second, are in operation on 11,000-volt single-phase 25-cycle railway service.[2] During the last two years, a need appeared for breakers of a time rating intermediate between that of standard breakers rated eight cycles and that of the special very expensive breakers rated three cycles. When the possibility of meeting this need was reviewed, it was natural to try to adopt, as far as applicable, the principles already established in the superspeed high-voltage impulse breakers. Pressure-generating breaks[3] were selected as the driving force for the oil blast rather than the mechanical driven piston of the impulse breaker. This method has the proved reliability of thousands of applications. In the absence of extreme speed requirements, this self-generated oil-blast action seemed to be fast enough.

High-voltage multibreak impulse breakers use a cylindrical insulating interrupting chamber in which a number of interrupting contacts connected in series are placed adjacent to port openings in the cylinder wall. The logical modification in such an interrupter to utilize the arc-pressure oil-motivating means was to associate a pressure-generating gap with each interrupting gap.

It seemed expedient to make such interrupters adaptable to conventional tank-type breakers because; first, it permitted the use of conventional bushing current transformers in place of the more expensive self-contained tripping transformers required by the high-voltage impulse breaker, and second, it made possible the modernization of large numbers of circuit breakers already installed so that operators could secure faster operating time without the expense of completely new apparatus.

Several different designs of multibreak interrupters of cylindrical shape adapted to tank-type breakers and utilizing the cross-blast principle with self-contained pressure generation, were subjected to interrupting tests at the high-capacity testing station at Schenectady. From those tests, the number of breaks required for various voltages was determined and the best features of all the types, such as shape, number, and location of port openings, were combined in arriving at a design which would interrupt effectively in minimum time.

Interrupters of the above described general design were subjected to many

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1. For all numbered references, see list at end of paper.

development in which we are interested.

In regard to Mr. Hunt's question as to how sure we are that the back-up breaker will take the rap and clear successfully in case of a failure on a test switch, the final answer to this question is that we are not positively certain. However, the back-up breaker used is one that has been in service and has performed successfully on many previous occasions during normal system operation and we have a fairly high degree of confidence that it will interrupt the short circuit. For one thing, the duty on the back-up breaker in such an event would be appreciably less than that involved in a quick clearing of the test breaker because of the longer time and resulting decrement. But, and this is more important, since the back-up breaker is one of the regular breakers on which is placed dependence for normal protection of the system, we feel there should be no question regarding its ability to handle the duty imposed upon it and if it is not capable of doing so, there really is no better time to find it out than under staged short-circuit conditions when everyone is on his toes and prepared for whatever may happen.

Mr. MacNeill has brought out a number of interesting points, particularly in comparing the present interrupter with the multibreaker design used in the Boulder Dam 287-kv breakers. Since most of these points have to do mainly with design details, I shall leave them for the consideration of the authors of our companion paper, Messrs. Spurck and Strang. Such discussions are always helpful in clarifying ideas and theories in connection with new developments.

Mr. Prince has pointed out that the circuit breakers installed on the Boulder Dam–Los Angeles 287-kv transmission line were not called upon to operate on a short circuit for nearly $1^1/_2$ years after installation. While we are not nearly so fortunate on our own system in having such infrequent faults, at the same time circuit breakers may wait a long time for anything like a severe test, first, because interrupting capacities are usually figured on a more or less future setup and, second, because even though faults may occur frequently enough, the location of these faults is rarely such as to give rise to the maximum possible fault current. This only confirms the wisdom of making system short-circuit tests to find out before one is lulled into a false sense of security and before there is a chance of an expensive failure, whether a given circuit breaker or circuit-breaker design is capable of performing as it is expected to perform.

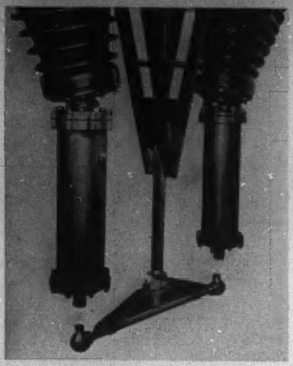

Figure 1. Six-break single-port interrupters installed on a 230-kv oil circuit breaker

interrupting tests at low currents and high currents in the Schenectady testing station. They were also given preliminary field tests before the final design was submitted for the field tests at Saugus and at Philo herein described.

In the tests at Schenectady, attention was not centered alone on the ability of the interrupters to handle heavy short-circuit currents but also on the ability to interrupt light currents as well. For example, the six-break interrupter was tested successfully on currents ranging from 20 amperes to 12,000 amperes and the four-break design from 25 amperes up to 27,000 amperes.

From those tests, it was determined that six breaks per terminal, that is, three pressure generating and three interrupting breaks, were adequate for 230 kv applications and four breaks for 138-kv service without resorting to voltage grading other than that resulting from the normal arrangement of parts.

Multibreak interrupters with cross-blast oil flow not requiring a mechanically driven piston for oil motivation and applicable to conventional tank-type high-voltage breakers are now available for breakers, or the modernization of breakers, rated from 115 kv to 230 kv in interrupting ratings up to 2,500,000 kva.

Description of Interrupter

A pair of these interrupters attached to one pole of a 230-kv oil circuit breaker is shown in figure 1. In figure 2 the interrupter is shown in cross section.

The main housing of the interrupter is a thick walled cylinder of insulating material having an unusually high dielectric and mechanical strength. This insulating housing is readily removable without removing the interrupter from the bushing. Figure 3 shows a six-break interrupter with housing removed and partially disassembled. When the housing is removed, all contact parts are still in place but exposed for inspection. Stationary members of the conducting parts are supported on four vertical insulating posts, each fastened at the top to the upper cover of the interrupter, and at the bottom to a retainer. Extending through the center of the interrupter is an insulating rod which carries the moving contacts. This insulating rod, which projects out of the lower end of the interrupter, terminates in a metal cap which is the contact engaged by the crosshead. A flexible lead from this cap carries the current from the cap to the main current path of the interrupter. Heavy pressure for each contact is obtained by inserting a spring between each contact and its fastening to the center operating rod. Interrupting contact faces are of Elkonite which is outstanding in its ability to withstand severe and repeated arcing with minimum loss of material.

When the breaker opens, the crosshead moves downward thus permitting a spring inside the interrupter to force the center rod supporting the interrupting contacts downward and part the contacts inside the interrupter. The arcs formed in the interrupter decompose oil into gas which creates pressure and forces oil out through the ports. The ports are so located in relation to the contacts that the flow of oil is directed between the contacts. Thus, during the time current is flowing, both oil and gas are flowing out of the port. As current zero is approached, less gas and more oil are carried over the contacts and out the port. It is important to bring out that the bleeding of gas from the interrupter takes place at the contacts adjacent to the port. Gas created at the contacts which have no port adjacent to them is stored in the chamber so that at current zero when no gas is generated, the stored pressure inside of the chamber is sufficient to drive oil into the space between the contacts adjacent to the port. Only a small contact separation is required, therefore, to allow sufficient oil insulation between the contacts to prevent the recovery voltage from breaking down the di-

Table I. Approximate Short-Circuit Values Obtainable by Variation of System Currents

Setup	Line to Ground Short-Circuit Current (Amperes)	Equivalent Three-Phase Kilovolt-Amperes
1	1,000	375,000
2	1,400	525,000
3	2,700	1,000,000
4	4,500	1,700,000
5	Line charging current approximately 50 amperes	

NOTE: Setup 1 utilized a feed from the 66-kv system through step-up transformers at Saugus to 220 kv. All other test arrangements, including that for line charging current, used lines of the 230-kv system only.

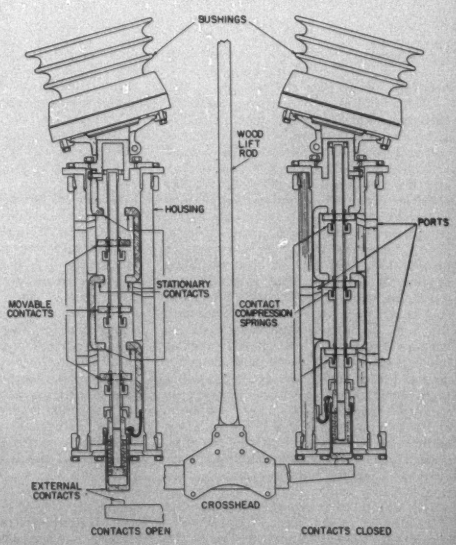

Figure 2. Cross section of six-break single-port interrupters for 230-kv oil circuit breakers. Contacts shown in open and closed positions

Table II. Interrupting Tests on a 220-Kv System

Test Number	Initial Voltage (Kilovolts)	Number of Ports Per Break	Tank	Duty**	Current Interrupted (Root-Mean-Square Amperes)	Equivalent Three-Phase Kilovolt-amperes	Breaker Interrupting Time (Cycles*)
1	216	1	A	Opening	1,032	386,000	4.22
1A	216	1	A	CO	1,010	378,000	3.74
2	216	1	A	Opening	1,414	529,000	3.57
2A	216	1	A	CO	1,414	529,000	3.44
3	216	1	A	Opening	2,680	1,000,000	3.5
3A	216	1	A	CO	2,680	1,000,000	3.27
4	216	1	A	Opening	4,400	1,640,000	2.96
4A	216	1	A	CO		1,760,000†	
15-second interval between tests 4A and 4A-1							
4A-1	216	1	A	CO	4,700	1,760,000	1.37
5	216	1	C	Opening	4,800	1,800,000	3.05
5A-1	216	1	C	CO	4,550	1,700,000	2.15
15-second interval between tests 5A-1 and 5A-2							
5A-2	216	1	C	CO	4,550	1,700,000	1.96
6	216	2	B	Opening	4,600	1,720,000	3.1
6A-1	216	2	B	CO	4,700	1,760,000	2.89
15 second interval between tests 6A-1 and 6A-2							
6A-2	216	2	B	CO	4,700	1,760,000	2.45

* 50-cycle system.
** Opening means breaker initially in closed position and tripped on occurrence of fault. CO means breaker is closed on a fault and then tripped open.
† No record. Estimated value.

electric between the contacts. This interrupting action is entirely in accordance with the oil-blast principle of interruption.

Proper arrangement of the port or ports in relation to the contacts results in an effective device which interrupts the current at an early current zero after the contacts part, as shown in the results of the field tests. Interruption of the circuit generally occurs before the crosshead contact parts from the exterior contact at the bottom of the interrupter. After interruption, the crosshead moves downward to the full stroke of the breaker, a distance sufficient to withstand the required insulation tests with the breaker in the open position.

Field Interrupting Tests at Saugus

On October 17, 1937, at the Saugus substation of the Southern California Edison Company, Ltd., a series of interrupting tests at 220 kv, frequency 50 cycles, was made on multibreak interrupters of the self-pressure-generating cross-blast type installed in a rebuilt triple-pole 230-kv type *FHKO*-139 oil circuit breaker having 108-inch-diameter round tanks. This oil circuit breaker was supplied in 1929. When originally put in service, it was equipped with plain explosion chambers for arc control and had an interrupting rating of 2,500,000 kva on the then standard CO–2 minute–CO duty cycle.

When tested, each pole of the breaker was equipped with six-break multibreak interrupters. Tanks *A* and *C* were provided with interrupters having single ports adjacent to each break and tank *B* with double ports. The original centrifugal-type closing mechanism was replaced by a cam-type mechanism of new design. This cam mechanism closes the breaker in about one-half second as compared with a closing time of about one second required with the original mechanism. Clear break distance from the external contact of each interrupter to the crosshead contact, with the breaker in the open position, was 32 inches. The six gaps of each interrupter add approximately 20 inches to that clear-break distance thus making the total clearance 52 inches from the live part of the lower end of the bushing to the crosshead in the open position.

Cam mechanisms for the operation of high-voltage breakers, are a recent development designed to improve on solenoid and centrifugal motor-type mechanisms in the following respects:

(*a*) Faster closing, or shorter closing time.

(*b*) Better proportioning of the driving output of the mechanism to the load requirements of the breaker.

(*c*) Lower operating currents for the same duty.

(*d*) Reducing slam and overtravel at the end of the closing stroke.

Figure 3. Six-break interrupter for 230-kv oil circuit breakers with housing removed and partially disassembled

Figure 4 shows a diagram of a cam motor mechanism of the type used on the test breaker. The driving element of

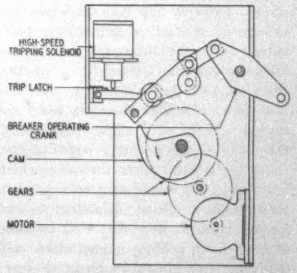

Figure 4. Diagram of cam-type operating mechanism for oil circuit breakers

this mechanism consists of a specially designed high-starting-torque motor arranged to rotate a cam approximately 270 degrees through a spur-gear reduction. Such a driving unit is substituted for the solenoid coil and plunger of solenoid mechanisms, thereby utilizing the same simple and reliable linkage used on modern solenoid mechanisms and retaining the feature of being mechanically trip-free in all positions. Tests show that these mechanisms which combine the features of the present improved solenoid linkage with the motor-driven cam, eliminate the slow starting of solenoids caused by the slow current build up and permit proportioning of the cam in accordance with actual output requirements. The result is the attainment of the objectives noted above.

The Saugus substation is a switching station for 66-kv and 230-kv lines. Oil circuit breakers and disconnecting switches in the station are so arranged that various lines entering the station can be connected individually or in combination to the test breaker in such a way that single-phase line-to-ground short circuits on the 220-kv system would produce approximately the equivalent three-phase values shown in table I.

All of the tests were made in one day.

No inspection of contacts or adjustments were made during the tests. Table II shows the results of the interrupting test, table III the charging current tests. The oil in all tanks tested at 30 kv between one-inch-diameter flat disks spaced 0.1 inch apart at the beginning of the tests and also at the conclusion of the tests. Oil color remained substantially unchanged during the tests. In order to check the condition of the contacts as the tests progressed, contact resistance measurements were made at frequent intervals during the tests. These tests were made by measuring the voltage drop across the breaker pole at currents of 400 amperes and 600 amperes. No change in contact resistance was indicated during or after the tests. Examination of the interrupters after the tests showed that they were substantially in the same condition as when installed. There was slight burning of the fiber burning plates opposite the contacts but the ports themselves had only slight discoloration over a part of their surface. Some insulation re-enforcing barriers were displaced because of inadequate holding screws which can easily be strengthened in future designs. Contacts were only slightly burned, as shown on the photograph of representative contact samples, figure 7. This contact burning is considered so minor that it is estimated that the contacts could have been subjected to ten times as many operations without impairing their current-carrying ability.

Oscillograms recording current, voltage, crosshead travel, trip coil current, etc., were taken for all short-circuit tests. Short-circuit currents transformed by a bushing-type current transformer and by a conventional wound transformer, were recorded on the oscillograph. The currents indicated by the bushing current transformer were, in general, slightly higher than those indicated by the wound transformer. Values shown in table I are calculated from the currents registered from the bushing-type transformer. The oscillogram of test 5A-2 shown on figure 5, is typical of those obtained on the short-circuit tests. This test is of particular interest in that it represents a CO test during which 1,700,000 kva was interrupted and which was made 15 seconds after test 5A-1 a CO operation interrupting 1,700,000 kva. In this latter test, the total time of short circuit was 2.56 cycles from the time the short circuit was established to interruption, including relay time.

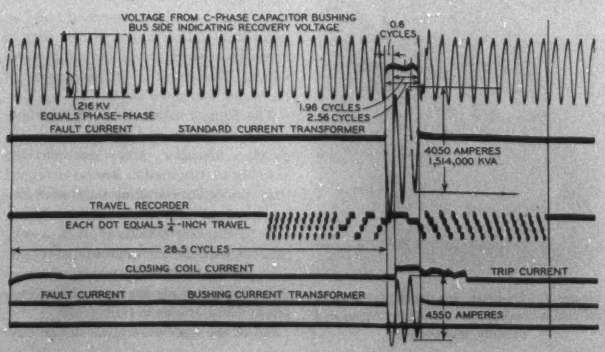

Figure 5. Oscillogram of test number 5A-2. Test breaker closed on, and interrupted a short circuit of 1,700,000 kva at 216 kv. Breaker interrupting time 1.96 cycles, total short-circuit duration 2.56 cycles. 50 cycle system

Line-charging-current test oscillograms included records of voltage, crosshead travel and the charging current in each of two lines. Oscillogram of test Number 8, an opening operation designated as figure 6, is representative of the line charging current tests. Although the oscillogram tells its own story, it is not considered superfluous to call attention to the disappearance of the normal-frequency current and the appearance of high-frequency high-current oscillations in the oscillograph line-current record after the breaker contacts parted. Furthermore, although the breaker interrupting time when interrupting line charging current (maximum recorded value 3.88 cycles) was longer than the breaker interrupting time on large short circuits, it was, nevertheless, slightly shorter than the interrupting time of the CO tests on short circuit of approximately 386,000 kva on which the breaker operating time was 4.22 cycles and which was the maximum value recorded for any test.

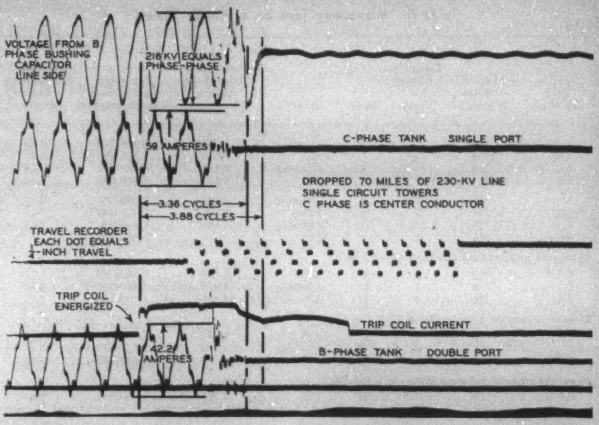

Figure 6. Oscillogram of test number 8 recording interruption of line charging current of 70 miles of line

Line voltage—216 kv
Current phase *B*—42.2 amperes
Interrupting time phase *B*—3.88 cycles
Current phase *C*—59.0 amperes
Interrupting time phase *C*—3.36 cycles
50-cycle system

Two series of 138-kv field tests were made on the four-break interrupters at the Philo station at The Ohio Power Company. The details of these tests including a description of the system setup and a tabulation of results are given in a companion paper by Sporn and St. Clair.[4]

Table III. Line-Charging-Current Interrupting Tests on a 230-Kv System

Test Number	Kilovolts	Number of Ports Per Break	Tank	Kind of Test	Line Charging Current (Amperes)	Breaker Interrupting Time (Cycles*)
7	216	1	C	Opening	43.2	3.08
7	216	2	B	Opening	57.0	3.08
8	216	1	C	Opening	59.0	3.36
8	216	2	B	Opening	42.2	3.88
9	216	1	C	Closing	57.6	
9	216	2	B	Closing	43.2	
10	216	1	C	Opening	No record**	
10	216	2	B	Opening	No record**	

* 50-cycle system.
** Same connections as for previous tests.

In brief, the tests were made on a new 1,500,000-kva 60-inch tank breaker equipped with a new high-speed trip cam mechanism and four-break interrupters which, in turn, were built with single port openings adjacent to each interrupting break and of somewhat lighter construction than those used on the circuit breaker tested at the Saugus substation. Twenty-one three-phase tests were made both opening and closing-opening (CO) at capacities ranging from 239,000 to 1,860,000 kva with no delay or inspection. Although the twenty-first test cleared the circuit without distress, it was found on the next test that one pole was open-circuited due, as found by later inspection, to a ruptured cylinder occurring on the twenty-first test.

After disconnecting two poles, including the damaged one, the tests were continued single phase to ground on one pole until on the twenty-fifth test at 1,910,000 kva, or 25 per cent above the rating of the breaker, the interrupters in this pole also suffered mechanical damage. However, the breaker interrupted the circuit in the normal time of 3.3 cycles with no outward evidence of distress.

Although these tests indicated gratifying performance at capacities considerably above the breaker rating and with maximum operating time of 4.6 cycles, it was considered quite obvious that certain modifications and additional tests would have to be made. Accordingly, after making two modifications in the interrupters—(1) increased size of vents to reduce pressures at high currents; and (2) slight rearrangement of insulating parts to obtain better arc control, a second series of tests was carried out on two poles only of the three-pole breaker, one pole equipped with interrupters modified by having two port openings, instead of one, adjacent to each interrupting break. These extra openings provide additional venting to relieve the pressure inside the cylinder, and at the same time the wall between them acts as an arc splitter, the efficacy of which has been demonstrated previously. The other pole was equipped with single port interrupters substantially the same as in the previous series of tests. After six two-phase-to-ground tests, going to values above the rating of the breaker, the single port interrupters again suffered mechanical damage and the tests were continued single phase to ground on the double port interrupters, completing the schedule of 13 tests without further trouble. In all of these 13 tests at duties from 382,000 to 2,030,000 kva, the maximum interrupting time was five cycles and out of the nine tests which were above 1,400,000 kva, the maximum time was 3.9 cycles. After these tests, the oil showed only slight deterioration, and, as in the case of the Saugus tests, the Elkonite-surfaced contacts showed practically no burning nor did any of the other parts of the interrupter show any deterioration or signs of distress.

Since 1926, three major series of oil-circuit-breaker interrupting tests have been made on the 138-kv system of the Ohio Power Company. Figure 8 compares the results of these three series of tests and shows a reduction in oil-circuit-breaker interrupting time that has been realized since the first series in 1926. Figure 8 also gives an indication of the increase in power concentration on the system. During the tests made in 1926 at Canton,[5] a circuit breaker equipped with plain explosion chambers interrupted up to 750,000 kva at 138 kv in 15 to 20 cycles. This represented a marked improvement in performance over the plain break contacts of an earlier day. By 1930,[6] about 1,750,000 kva was available for field testing at Philo, and oil blast chambers gave over-all operating times of eight cycles or less. In 1937, the system short circuit had grown to over 2,000,000 kva, providing the largest amount of power ever made available for oil circuit breaker field tests. During these tests, the double-port multibreak interrupter successfully cleared all currents over this range with a maximum breaker interrupting time of five cycles. Contrary to what might be expected, there is scarcely any measurable difference in breaker interrupting time of the single and double port interrupters.

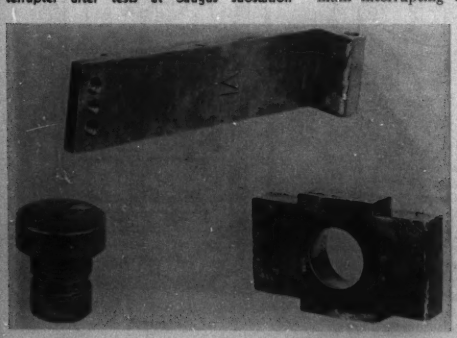

Figure 7. Representative contacts of interrupter after tests at Saugus substation

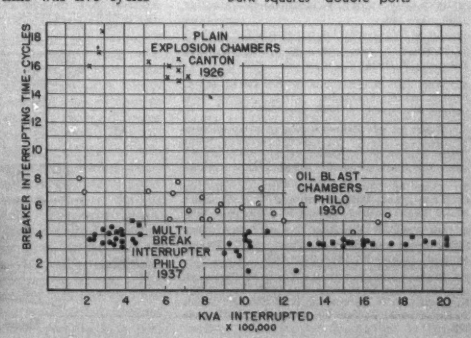

Figure 8. Comparison of oil circuit breaker interrupting time as shown by tests on a 138-kv system

Dark circles—single ports
Dark squares—double ports

The consistency of performance is best indicated by the fact that above 1,300,000 kva every operation fell in a narrow band between three and four cycles.

Conclusion

The multibreak interrupter follows logically the development of earlier oil-blast chambers and the superspeed impulse breaker. Proved by both laboratory and field tests, it makes available performance closely approaching the impulse designs for voltages 115 kv and above, but in circuit breakers of relatively conventional and inherently less costly design. It also affords a means of obtaining the advantages of this still higher speed operation on many breakers already in service when changing system conditions indicate such a need. Many existing circuit breakers may be modernized with these chambers to secure the superior performance demanded by a progressive and growing industry.

Acknowledgment

The authors thank and express their appreciation to the organizations of the American Gas and Electric Company, the Ohio Power Company, and the Southern California Edison Company, Ltd., whose courage, planning, and co-operation made these tests possible. It is a distinct tribute to the sound engineering and planning of the designers and operators of those systems, that system short-circuit tests involving short-circuit values of approximately 2,000,000 kva were made without delay, slight system disturbance, and no interference with customer's service. Tests of this kind are potent factors in the development of apparatus adequate for the present day high standards of system operation.

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Discussion

J. B. MacNeill (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The paper by Spurck and Strang and that by Sporn and St. Clair, both on the subject of high-voltage circuit interruption, are valuable additions to this art and demonstrate a high grade of ability in modern interrupters built along conventional lines.

It has been realized for some years that to obtain maximum interrupting speed on high-voltage circuits it is necessary to introduce multiple breaks. The idea of using groups of series interrupters isolated in the open position by a moving contact arm was developed several years ago.

Figure 1 of this discussion shows an early construction of this method. By it is obtained the necessary increase of total contact speed while maintaining reasonable velocities of the heavier moving parts. The follow-up action of the moving contact establishes a large open break after interruption has taken place. A construction having adequate 60-cycle and impulse voltage tests is thus secured with the required high speed of circuit interruption. Since the weight of moving contact material approaches that of an ordinary two-break device, there is no sacrifice in the closing speed necessary for synchronizing and high-speed reclosure.

An outstanding application of this principle was employed in the 287,000-volt breakers at Boulder Dam, which were covered in the paper by Wilcox and Leeds, presented at the Pasadena convention in 1936. Figure 2 shows the arrangement of contacts there used. With this construction circuit breaker times of well under three cycles have been obtained for the highest commercial voltages. Figure 3 shows an oscillogram of one-half a pole unit opening 2,900 amperes at 132 kv at a total time of 2.45 cycles on a 60-cycle circuit.

There has been some speculation as to the possibility of securing this type of performance in dead-tank structures at high voltages. Previous AIEE papers have referred to the unequal distribution of voltages between breaks, particularly with grounded short circuits. No particular means for taking care of this problem is evident in the design described by the authors. We would like to have their ideas as to the voltage distribution which takes place between the breaks with their designs under different conditions of short circuit. Is 90 per cent of the voltage across the ungrounded side in case of a grounded short circuit?

Means for securing suitable voltage distribution in such structures have been

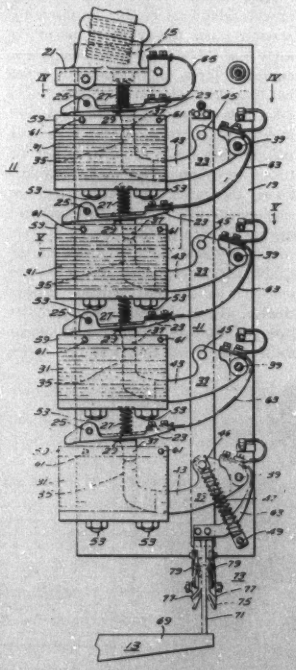


Figure 1

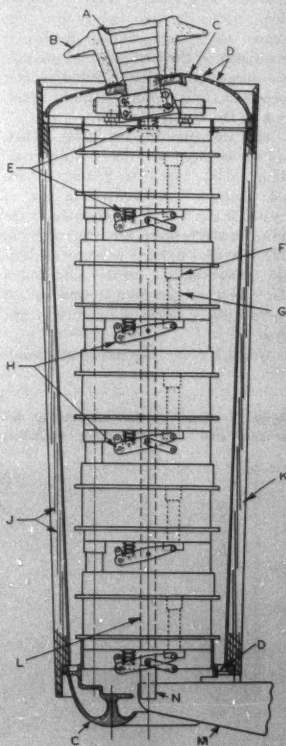


Figure 2

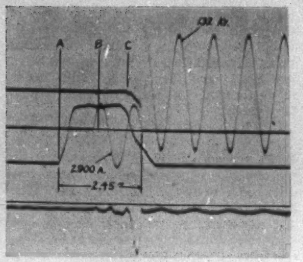


Figure 3

known for years and are useful in securing 60-cycle voltage tests and impulse tests as well as during arc interruption. Figure 4 shows a disclosure of the fundamental idea of electrostatic distribution between arcs as applied to oil circuit breakers made approximately ten years ago. The complete theory was covered in an AIEE paper by R. C. Van Sickle published in ELECTRICAL ENGINEERING for August 1937.

The papers by Sporn and St. Clair and by Spurck and Strang are noteworthy as showing variations of the construction referred to above and also applied to dead-tank circuit breakers. We hold that it is fortunate that the improved operation cited in the test results given in these papers has been obtained in conventional constructions which have a direct bearing on many existing American high-voltage stations, and which are usable in much old apparatus, as well as that offered for future sale. It would be unfortunate if ideas previously expressed to the effect that high-speed operation is obtainable only in porcelain structures should gain ground. The work of the past four years points to the conclusion that the highest grade of switchgear performance is obtainable, and with large factors of safety, in a standard dead-tank unit.

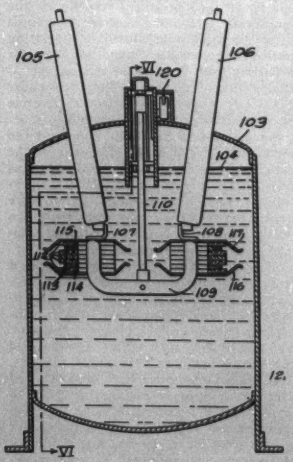


Figure 4

The writers speak of the 138-kv breaker as a four-break design and of the 230-kv type as a six-break design. They refer, in using these designations, to the number of points at which circuit rupture is accomplished. However, it seems to me that the 138-kv design has 10 breaks, consisting of 4 circuit-interruption breaks, 4 gas-generating breaks and, in addition, the 2 long isolating breaks. In the same way the 230-kv design has 14 breaks consisting of 6 circuit-interrupting breaks, 6 gas-generating breaks, and the 2 isolating breaks. Since the circuit presumably is interrupted in practically all cases before the isolating breaks get under way, there will be no contact depreciation at these points, but the other breaks share equally in contact burning and oil depreciation and we feel therefore that both the circuit-interrupting breaks and the gas-generating breaks should be recognized.

Both designs incorporate a number of breaks in a single container and reference is made in each paper to difficulties with this container during the process of development. Failure of the container places one-half of the pole unit out of service. Would not a rearrangement of the interrupters in individual containers, such as shown in the design of figure 2 give greater mechanical strength and greater assurance of operation in case of breakage of an individual unit?

W. F. Sims (Commonwealth Edison Company, Chicago, Ill.): The papers presented by Mr. Spurck and Mr. Sporn cover the development and test of an important advance in the art of arc interruption and bring to mind a few thoughts that should be of interest in this connection.

During the long period of financial stress to which we have all been subjected the manufacturers have gone steadily ahead with constructive research and development in bringing out improved devices of greater interrupting duty and shorter arcing time. They should be commended for their foresight in carrying on this work under adverse conditions, which insures to the utilities the availability of new equipment to meet the more severe and ever changing requirements. Because of this attitude on the part of the manufacturers we can have full confidence that new equipment will continue to be produced as required.

In connection with the tests on this equipment, it is a noteworthy fact that these two companies had such confidence in the soundness of the design and in the integrity of construction of their systems as to be willing to permit short circuits to be placed on their systems under maximum conditions. Much credit is due these companies for their courage and willingness to carry out these tests in the field under the conditions to be met in actual operation.

The high-power laboratories at the factories, which represent large investments on the part of the manufacturers, are of great value in the working out of new designs and in testing their component parts. However, it is not economically feasible to provide laboratories that would subject the equipment to the same conditions that would have to be met in service. The interests of both the manufacturers and the utilities are very greatly advanced because of the willingness of these companies to permit these field tests to be made upon their systems.

It is important to note that the manufacturers in their developments have designed these improved arc interrupting devices in such manner that they can be used to replace corresponding parts of older design and can be installed within the structures of existing equipment. This is an economic achievement which will save the utilities large investment expenditures when the breakers now on their systems become inadequate to meet the more severe conditions brought about by system growth.

E. E. George (Tennessee Electric Power Company, Chattanooga): One of the most interesting features of high-speed breakers associated with high-speed relays is the ease with which staged tests can be made on week days during peak load conditions at any point on the system. When making staged tests ten years ago it was frequently necessary to select an isolated corner of the transmission system, provide a special generating setup, change many relay settings, and schedule the tests between midnight and 5:00 a.m. on Sunday or Monday when the industrial load would be at a minimum. Even then power sales departments and customers' electricians needed considerable reassurance.

With eight-cycle breakers and high-speed relay, tests are now made satisfactorily during peak load periods at the heart of the system without disturbance to customers and without re-arrangement of system connections or generating setup.

H. A. Lott (Southern California Edison Company, Ltd., Los Angeles): Engineers of the Southern California Edison Company, Ltd., have been interested in the modernization of existing 220-kv breakers as an essential part of the program for continued improvement in continuity of service. The first step in the program of modernization was made in 1932, when six 220-kv breakers were rebuilt on the basis of 12 cycles, on a 50-cycle base. Subsequent development and experience resulted in revised specifications calling for eight-cycle interruption, whereas more recent development and experience indicated a still further reduction in over-all time of clearing not to exceed five cycles as being the probable practical limit for the clearance of short circuits by the addition of modern interrupters to existing breakers.

The modernization program has continued since 1932. At present, 62 out of a total of 103 220-kv breakers have been rebuilt to 12 cycles or better. The program has progressed at a conservative rate in order to take advantage of new developments, and also to receive some operating experience with higher speed clearances, which would tend to establish a practical balance between the added cost of still higher interrupting speeds and the necessity for such higher speeds.

The Southern California Edison 220-kv system is characterized by extensive high-voltage transmission lines. The generation is predominantly hydroelectric, with 399,000 kilowatts concentrated in the five Big Creek plants located 250 miles from the load center. The hydro generation is supple-

mented by 355,000 kilowatts of steam generation located at Long Beach, 25 miles from the load center. These two major plants, which are 275 miles apart, are interconnected with 825 circuit miles of 220,000-volt transmission line. This portion of the system, together with the seven step-down substations and 400,000 kvs of synchronous condenser capacity, must transmit and transform 85 per cent of all of the energy generated by the Edison system.

The importance of fast clearances on this system is evident when under maximum short-circuit conditions of $2^1/_4$ million kva an over-all clearance of five cycles is required in order to prevent instability following multiphase short circuits during heavy load conditions. During the past six years, 116 short circuits have been cleared from the 220-kv system. Four of the short circuits started multiphase, while 11 of the short circuits developed into multiphase after an average duration of about 15 cycles; the remainder were single conductor to ground short circuits. If it is possible to clear all faults in 12 cycles, we can expect to have two cases of instability each three years, based on the past six years experience, whereas clearances in the order of 5 to 8 cycles would be expected to eliminate most of the cases of instability caused by short circuits which start multiphase.

Since the program of rebuilding breakers was started, it has been found that the damage at the point of fault is now practically negligible, when the clearance is effected in 15 cycles or less. The damage at points of flashover is so slight that it is now necessary to climb towers and make a close inspection in order to locate the trouble. An effort is now being made to determine the approximate location of such faults by utilizing recorded values of ground current.

In order to assist in the development of high-speed interrupters, it was realized that it would be necessary to supplement factory tests, where certain limitations in both voltage and capacity exist, by field tests under actual operating conditions, where maximum short-circuit duties of $2^1/_4$ million kva were available. Accordingly, the first series of field tests at 220 kv were made at our Saugus substation in October of 1936, when a total of 15 short circuits, varying from 300,000 kva to 1,700,000 kva were made without indication of instability or without inconvenience to consumer's service. From these tests, it was evident that if the over-all time of clearance was in the order of five to eight cycles, similar tests could be carried to the maximum values of $2^1/_4$ million kva without instability or inconvenience to consumer's service.

Subsequent to the 1936 tests, the first series of tests on the "New Multibreak Interrupter" described in the paper presented by Messrs. R. M. Spurk and H. E. Strang, were made in April of 1937, with short circuits varying from 300,000 kva to 1,700,000 kva. These tests proved the electrical performance of the new interrupter, but indicated a mechanical weakness that could be readily overcome. The second series of tests on this type of interrupter was made in October of 1937, with the results as described by the authors.

During the tests at Saugus, the system generating capacity, interconnected during each test, was 560,000 kva; of which 360,000 kva was at Big Creek, 210 miles from the point of fault, and 200,000 kva was at Long Beach, 65 miles from the point of fault. Including the synchronous condenser capacity of 400,000 kva, which was in operation at the time of test, the total synchronous capacity was 960,000 kva.

The Saugus 220-kv construction is our standard 220 kv double-bus construction with two breakers, one to each bus for each position, which greatly facilitated the switching necessary to obtain the various values of short-circuit current. A complete duplicate opening and closing circuit for both the test and back-up breakers, together with the test relays, oscillograph, etc., were set up in a temporary relay house just outside the bus yard. A portable dark room was installed near the relay house to provide facilities for developing films between each test. The several values of short-circuit current were obtained by opening lines of different lengths from the load bus and closing them to the test bus at Saugus. The maximum values were obtained by paralleling the load bus and the test bus.

The test was completely planned and a printed program giving each step in the operating procedure was distributed to the system dispatchers, and all operators concerned in advance of the test. Telechron clocks were synchronized before the test started, and the 220-kv station operators were notified about five minutes prior to each test, of the exact time of each test. One man was selected to maintain all contact between the test location and the system load dispatchers, so that after each system setup had been completed, a time was selected and the short circuits applied without further instructions. As a result, the tests progressed rapidly. Four different line and bus arrangements were made to obtain the short-circuit-current values, and 15 short circuits were imposed and cleared between 9:15 a.m. and 2:00 p.m.

The results, from an operating standpoint, were ideal in every respect. There was no dip in system speed, and a maximum voltage dip of only 7 per cent was recorded under the most severe condition. There were no consumer complaints, since in every one of the 15 cases, the short circuit was cleared with but a barely perceptible flicker of consumer's lights. It was again established that short circuits would not impose an inconvenience to consumer's service if cleared by high-speed relay and breaker operation. The performance of the switch was such that following an inspection of the contacts, the breaker was placed in routine service without requiring any further adjustments.

The authors are to be congratulated for their presentation of such an interesting paper, marking another step toward better continuity of service through the medium of improvement in circuit breaker design.

A. C. Schwager (Pacific Electric Manufacturing Corporation, San Francisco, Calif.): It is gratifying to notice the improvement obtained with the fast-clearing circuit breaker described by the authors over the two-break oil-blast breaker. The reduction in opening time is accomplished mainly by the use of the multibreak principle which seems to become the conventional means among all manufacturers for obtaining fast interruption. For an analysis of the effectiveness of the device described it would be interesting to know the arcing times present during the interruptions listed in table II and the possible improvement in performance if potential grading had been used.

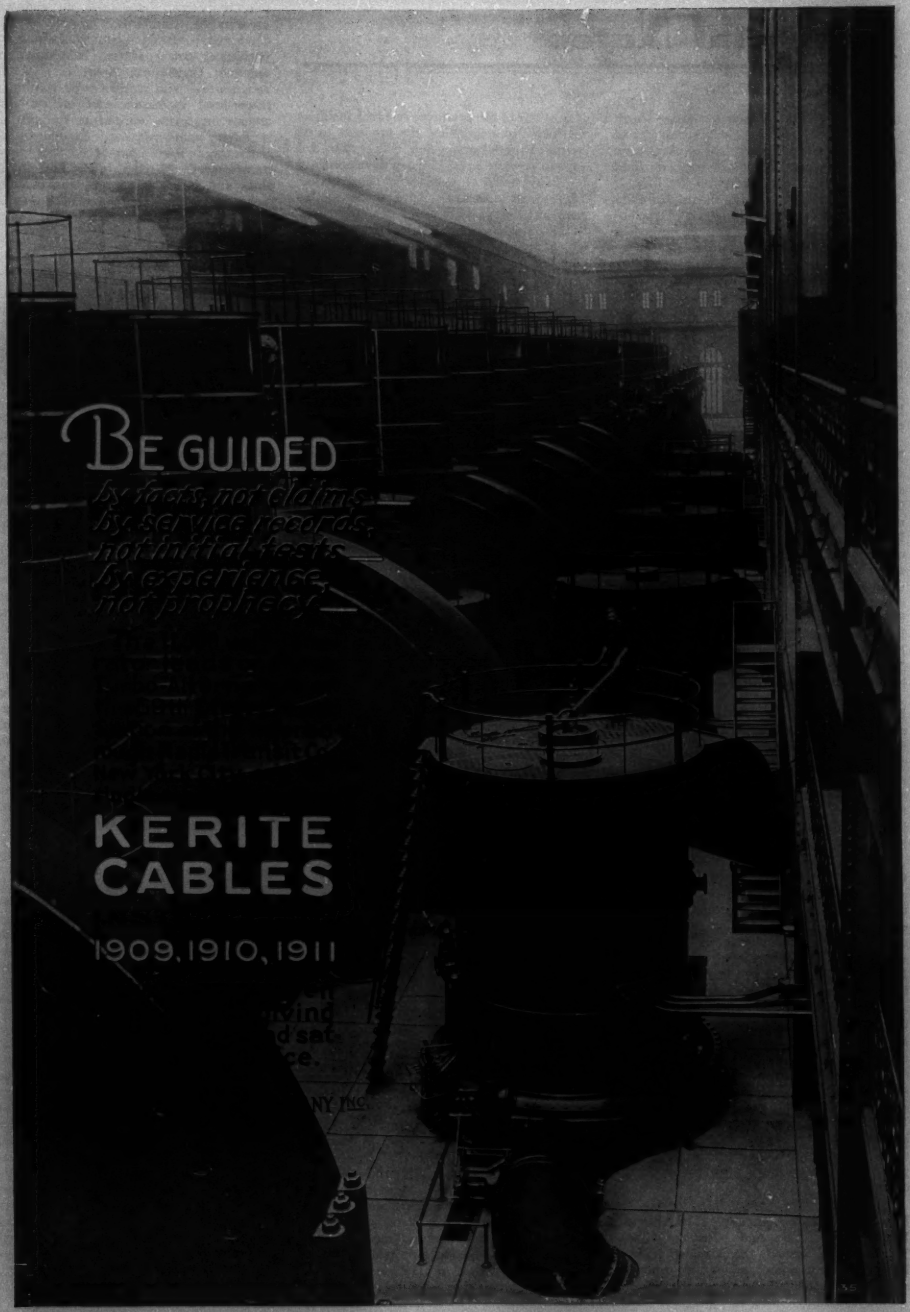
R. M. Spurck and H. E. Strang: We appreciate the constructive and interesting discussions presented on this paper. The discussions of Messrs. George Lott and Sims add materially to the paper and do not seem to require any further discussion from the authors. Mr. Lott's comments are of particular importance as they apply to the Southern California Edison System on which the 220-kv tests were made.

Messrs. MacNeill and Schwager ask about the potential distribution across the contacts. As stated in the paper, no means for grading the voltage across the various breaks was provided except that resulting from the normal arrangement of parts. The natural grading so obtained was so effective, as evidenced by the excellent performance of the breaker, that the additional application of artificial grading was not justified. In general, the arcing times obtained during the tests listed in table I were between one-half cycle and one cycle.

We emphasize that breakers with this type of interrupter are intended for five-cycle operation. Breakers for three-cycle operation at 287 kv, as used on the Boulder Dam, Los Angeles line, are of the impulse type described by Mr. D. C. Prince before the Institute in 1935. (D. C. Prince, "Circuit Breakers for Boulder Dam Line," AIEE TRANSACTIONS, volume 54, 1935, page 366). In that paper, the results of various tests are listed. One test shows one-half of one pole of the breaker clearing 730 amperes at 264 kv in 2.45 cycles. That performance is much better than the performance shown on the oscillogram presented by Mr. MacNeill in his discussion, where one-half of a pole unit of a 287-kv breaker interrupted 2,990 amperes at 132 kv in 2.45 cycles. Even though the multibreak interrupter cleared the circuit in all cases substantially under its rating of five cycles, we have found no reason for departing from the impulse-type porcelain-clad breaker of the type used on the Boulder Dam, Los Angeles line when three-cycle operation at high voltage is required.

Some question has been raised on the number of breaks used. The text of the paper and the captions of the illustrations refer to the number of breaks per interrupter. Thus, if six-break interrupters are used as for the 220-kv tests, there are twelve breaks total in the two interrupters in addition to the isolating breaks.

Mr. MacNeill discusses the advantages of multibreak interrupters which do not require main moving contacts more complicated or heavier than those used in conventional two-break tank-type breakers. The multibreak interrupters described in our paper have such desirable features. Also, these interrupters have been designed with one housing surrounding a group of breaks rather with one housing for each break or pair of breaks in the interest of greater strength of the housing, simplicity of construction, and ease of housing removal for inspection.


BE GUIDED
by facts, not claims—
by service records,
not initial tests—
by experience,
not prophecy—
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CABLES
1909, 1910, 1911

Industrial Notes

Leads In Rural Electrification.—North Carolina now leads the south in number of customers being served by rural electric lines, with a total of 45,425 users on lines either built or authorized up to July 1, 1938, according to the North Carolina Department of Conservation and Development. In 1937 North Carolina ranked in fifth place in the U. S. in number of farms electrified. In the three years preceding July 1938, more than 7,000 miles of rural electrification lines have been completed and more than 1,000 miles were under construction or authorized. Of these lines, 6,467 miles were built or authorized by the public utility companies operating in that state, while 565 miles were built or authorized by municipalities; 1,151 miles were built or authorized by the Rural Electrification Administration.

Marine Order to Westinghouse.—The sale of nearly a million dollars worth of propulsion and other marine gear to the Standard Oil Company of New Jersey was effected recently by the Westinghouse Electric & Mfg. Co. This material will be used in the outfitting of a fleet of twelve new twin-screw oil tankers. These ships will be notable for their speed—18 knots trial speed when fully loaded. The tankers will be propelled by high pressure steam turbines developing 13,500 shaft horsepower. Each vessel will have an overall length of 551 feet and a cargo capacity of 145,000 barrels.

New Industrial Glass Division.—The Anchor Hocking Glass Corporation, Lancaster, Ohio, has established a new industrial division to cooperate with manufacturers in promoting the use of glass for many industrial purposes. In the electrical field the company is prepared to produce glass in practically all forms for insulating parts, meter covers and other uses.

General Electric Appointment.—O. H. Van Amberg, engineer of wiring systems for the General Electric construction materials division, Bridgeport, Conn., has been assigned to special duties in connection with all U. S. Government bureaus and Federal projects, and will henceforth make his headquarters in Washington, D. C.

Ohio Brass Appointment.—Claude R. Kingsbury has been appointed representative, with headquarters in Seattle, Wash., of the Ohio Brass Co., Mansfield, O. He succeeds J. W. Watkins, resigned. Mr. Kingsbury has been with Ohio Brass since 1927, first at the Barberton insulator plant, in charge of the electrical laboratory and more recently at the Mansfield plant engaged in street railway and trolley coach engineering.

New Fiber Glass Company.—The Owens-Illinois Glass Co. and Corning Glass Works have formed the Owens-Corning Fiberglas Corporation, which will produce a variety of products made from fiber glass. The result of the extensive research facilities of these two companies, the products to be manufactured by the new corporation are said to promise revolutionary developments in many fields of insulation, construction and industrial design. Applications in the electrical industry are covered in an article "Fibrous Glass for Electrical Insulation," which appears in this issue, beginning on page 480.

Trade Literature

Voltage Regulators.—Bulletin 2326, 4 pp. Describes rocking contact voltage regulators for automatic control of small a-c and d-c generators. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Welding Accessories.—Bulletin 401, 36 pp. Describes arc welding electrodes and accessories, and outlines procedure for the welding of various metals. Lincoln Electric Co., 12818 Coit Road, Cleveland, O.

Zinc Castings.—Booklet, 24 pp. Describes and illustrates the use of zinc alloy die castings in industrial equipment. The New Jersey Zinc Co., 160 Front St., New York.

Sectionalizer.—Bulletin, 4 pp. Describes "Line-Arc" repeating sectionalizer for the protection of d-c sectionalized power circuits in mines and for protecting power feeders for cranes, crane runways, etc. The Electric Controller & Mfg. Co., Cleveland.

Industrial Vacuum Cleaners.—Bulletin A-303, 8 pp. Describes heavy-duty, industrial portable vacuum cleaning units. United States Hoffman Machinery Corp., 105 Fourth Ave., New York City.

Synchronizers.—Bulletin 1193, 8 pp. Describes the "Synchro-Operator" for automatically paralleling a-c generators, synchronous condensers, tie lines and frequency changers. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Magnetic Clutches.—Bulletin 225, 16 pp. Describes magnetic clutches and combination clutch brakes; applications are illustrated. Stearns Magnetic Mfg. Co., Milwaukee, Wis.

Laboratory-Industrial Equipment.—General Radio catalog "K," 216 pp. A comprehensive volume describing in detail, with prices, a wide line of industrial and laboratory apparatus. Industrial devices include Stroboscopes (for observing and measuring fast moving operations in slow motion); Sound level meters, analyzers, d-c amplifiers and Variacs (recently developed type of a-c voltage control). Other sections are devoted to Decade resistors, resistance units, volume controls, rheostat-potentiometers; Capacitors, air and mica capacitance standards, general purpose condensers; Bridges for measuring capacitance, power factor, inductance, resistance; Oscillators; Amplifiers; Meters, vacuum-tube and rectifier-type voltmeters, power-level indicators and others; Frequency measuring equipment, primary and secondary standards, etc.; Standard-signal generators; Parts and accessories, audio transformers, switches, dials and knobs, plugs and jacks, coil forms, chokes, relay racks. Reactance charts and decibel tables are included. General Radio Co., Cambridge, Mass.

Rectifiers.—Bulletin R-38, 8 pp. Describes recent developments in dry metallic rectifier construction, their application and performance. Rectifiers and filter circuits are discussed and typical ratings shown. New developments include heavy duty single stack rectifiers and forced draft cooled units. The B-L Electric Mfg. Co., 18th & Washington Ave., St. Louis, Mo.

Switchboards.—Bulletin 385, 8 pp. Describes "Vacu-Break" switchboards, constituting a more compact, modernized type of feeder distribution center and featuring quick-make and quick-break switching, with positive arc control. Bull Dog Electric Products Co., Detroit, Mich.

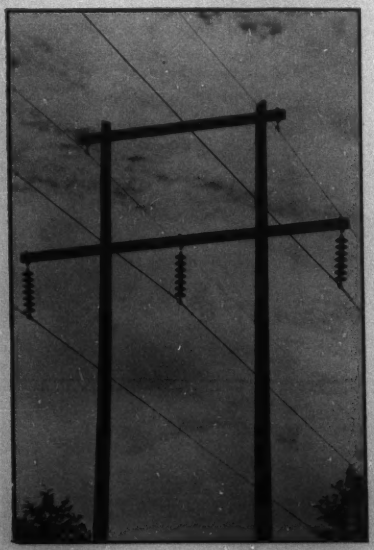
Guy Strands.—Bulletin E. D. 1686, 8 pp. Contains tabular information on the physical properties of guy strand, and notes on installation practices; includes a convenient, graphical method of determining the required strength of guys. Copperweld Steel Co., Glassport, Pa.

Insulation Testers.—Bulletin 405, 4 pp Describes type "OK" megohmmeters for insulation testing. The instruments are made up with either 220-volt or 500-volt d-c generators, and with a range of either 20 or 50 megohms. In addition, some of them are arranged with voltmeter scales so as to permit their use as a-c and d-c voltmeters. Herman H. Sticht & Co., 27 Park Place, New York City.

Potentiometer.—Cat. E33A (1), 12 pp. Describes a new Wenner potentiometer for the measurement of thermocouple and other voltages; range 0 to 0.11111 volt. Fully outlines the Wenner principle and its application; includes data about materials used and the reasons for their use, describing how thermoelectric forces within the instrument are suppressed and compensated for. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Power Transformers.—Bulletin DD 211, 16 pp. Describes completely self-protecting power transformers designed to provide a better standard service through a lower first cost installation than the equivalent rating in a conventional substation. These transformers are available in 1000 kva, OISC, 3 phase, 60 cycles, 55° C. temperature rise, high voltage 13,200–13,860–12,540 F.C. delta, low voltage 4160 star, 4-wire. They incorporate such features as automatic tap changing under load equipment, low voltage switch, thermal protection, lightning protectors and metering. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

. . . the trouble that never happened



PLENTY of trouble for Baldy. But none on the A.C.S.R. lines, so the little game he started, "to trim the pikers," lasted all night. He's had a rough going over.

You learn to expect a minimum of trouble when the conductors on your hi-lines and rural lines are Aluminum Cable Steel Reinforced; no need to have your gangs up all night waiting for trouble. Operating men everywhere report regularly that their A.C.S.R. lines have gone through serious ice, wind and electrical storms without injury.

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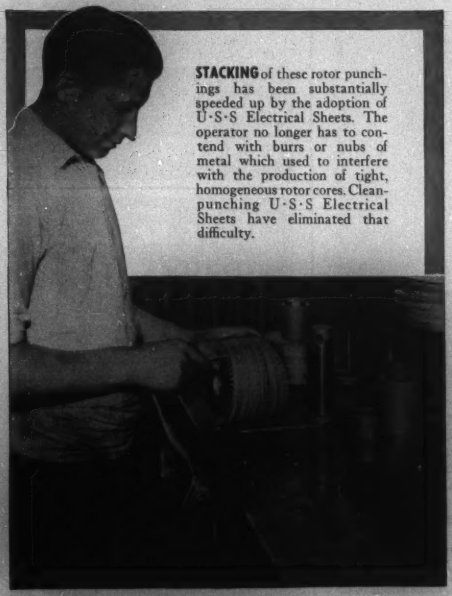
PUNCHING becomes relatively inexpensive when you reduce die wear and eliminate readjustments due to changes in the steel by using U·S·S Electrical Sheets. This blanking die for punching 16-gauge pole-piece laminations was carefully "miked" after 1000 punchings. It showed no apparent signs of wear.

GAUGING is practically a mechanical operation in shops where U·S·S Electrical Sheets are used. Because these sheets are inherently flat and true to gauge, the lamination stacks are always solid and uniform.

You Can *SAVE* with U·S·S Electrical Sheets!

1. PUNCHING

The correct grade of U·S·S Electrical Sheets saves money in punching because of the uniform quality of the steel—every sheet is true to standard. They all punch cleanly without causing excessive die wear. You get more laminations from a given press setup. Once adjusted, the press needs no further adjustments because of variations in the steel.



STACKING of these rotor punchings has been substantially speeded up by the adoption of U·S·S Electrical Sheets. The operator no longer has to contend with burrs or nubs of metal which used to interfere with the production of tight, homogeneous rotor cores. Clean-punching U·S·S Electrical Sheets have eliminated that difficulty.

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Laminations that are punched cleanly, with no protruding burrs or metal nubs, stack much more easily. That's why one workman can turn out more cores per day when he is stacking laminations punched from U·S·S Electrical Sheets.

3. GAUGING

U·S·S Electrical Sheets are always uniformly flat and true to gauge. This keeps space factor to a maximum and speeds up the gauging operation.

Choosing the right grade of electrical steel, and then seeing that it is correctly used, is a job that requires a rare combination of talents. To do this job speedily and eliminate costly errors requires a man who knows electrical steels from A to Z, and who also knows electrical manufacturing practice. Such men are our Electrical Sheet Specialists. We offer you their cooperation. Next time you meet a problem involving the selection or application of silicon-steel sheets, call the man from Carnegie-Illinois.

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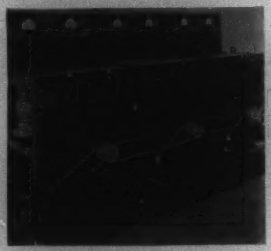
UNITED STATES STEEL

New Products

Arc Welder.—The new "Alternarc" machine, type W, is designed to supply for a-c welding purposes an "uninterrupted infinite variation of both current and voltage, with the proper voltage automatically

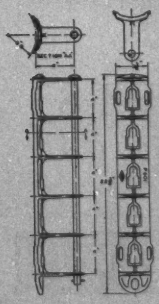


supplied for each current," according to the manufacturer, the Electric Arc Cutting and Welding Company of Newark, N. J. This continuous constant-energy control is said to result in important economies in power consumption, and also in constant heat at the point of weld. Improvement in power factor also is claimed. The continuous rather than step-by-step control is effected through a control coil in the transformer and a movable portion of the transformer core. The illustration shows a 1,500-ampere assembly made up of three 500-ampere units.

Pothead.—The G & W Electric Specialty Co., Inc., Chicago, is offering a new pothead, type "T," outdoor capnut, single conductor, 7,500-volt, 250- and 500-ampere. Features include solderless clamp style internal and external connectors using a separate clamping plate which accommodates one range of conductor sizes in one position and another range of conductor sizes with the clamping plate reversed. The one set of connector parts takes care of an unusually large range of cable sizes. The external lug is designed so that the aerial conductor can be clamped vertically or horizontally by merely turning the clamp plate 90 degrees. The base sealing fitting is a stuffing box style, using oil-proof, molded rubber squeeze bushing. The hole in this bushing need only be varied for different cable diameters.

Small Mercury Arc Rectifier.—A small capacity, permanently evacuated rectifier unit using a glass heat-resistant bulb as a vacuum chamber, has been placed on the market by the rectifier division of the Allis-Chalmers Mfg. Co., Milwaukee, Wis. These new rectifier units require neither vacuum pumps, vacuum gauges, nor cooling water, being air-cooled by means of a small fan, and are available in sizes ranging from 50 kilowatts, 250 volts, to 300 kilowatts at 600 volts, or even higher voltages, furnished in factory wired and assembled cubicles. The necessary transformers and circuit breakers may be placed in any convenient

location adjacent to the cubicle. For larger power requirements several units may be operated in parallel. They are especially adaptable to small traction systems and to industrial loads of moderate d-c power requirements. Where change-overs from direct to alternating current are being made, such rectifier units often permit economical continued use of existing d-c equipment.



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Produced by established manufacturer of Williams Pole Mounts, Pole Stubbing Clamps, Aerial Cable Messenger Clamps and Insulated Hangers, Malleable Crossarm Gains, Transformer Gain Plates and Kick Arms, Through-bolt Guying Devices, etc.

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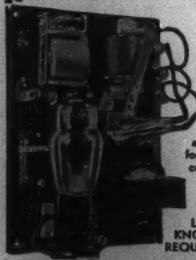

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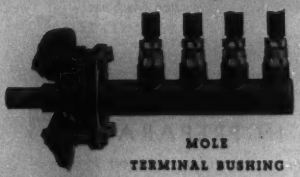

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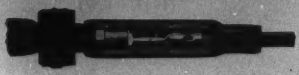
TERMINAL BUSHING

Left: Burndy Studmole, a combined insulated multiple terminal and bushing. Replaces porcelain bushings and gaskets on network protectors, seals out moisture and gas, provides many connections in limited space.



MOLIMITER

Burndy Limiter Lug installed at Mole outlet and insulated by Asbestite shell and rubber jacket. Especially useful for fusing cables at network junction points.

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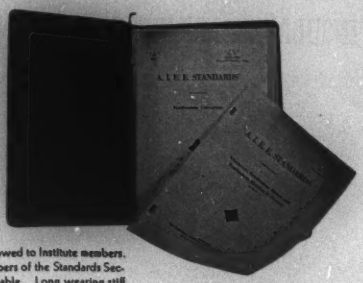
THE Standards of the American Institute of Electrical Engineers now comprise forty-six sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



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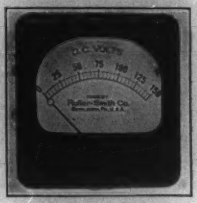

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B.E., married; 28 yrs gen consulting exper in elec, mech, chem fields; investigations; reports; research; constr; Diesel pwr plants, air conditioning instal; NY State license. Prefers NYC. E-355.

B.E., located in England, is interested in representing a pub util corp in Britain, India or China. E-352.

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B.S.E.E., 1936, 25, single, member Eta Kappa Nu. Student course large radio corp; one yr in research dept as test engr. Interested in radio, television or electronics research. E-358.

B.S.E.E., '38, Univ of Iowa; age 23, member Tau Beta Pi. Conscientious; desires pos in elec field, com preferable. Anything elec considered. Location immaterial; salary secondary. Available immed. E-361-9775-Chicago.

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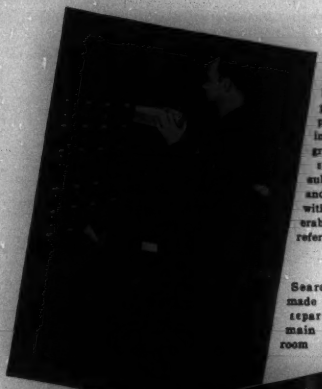

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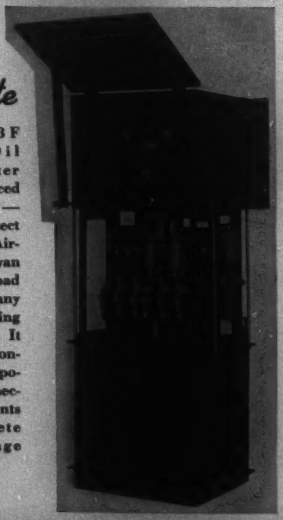

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A simple, direct and accurate method of determining the voltage distribution across multishell high-voltage insulators is provided in the use of the General Radio Type 740-B Capacitance Test Bridge.

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GENERAL RADIO COMPANY

Cambridge, Massachusetts

BRANCHES: NEW YORK AND LOS ANGELES

MANUFACTURERS of PRECISION ELECTRICAL LABORATORY APPARATUS

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1938 Marks Our 60th Year of Service

THE OKONITE COMPANY

Founded 1878

EXECUTIVE OFFICE: PASSAIC, NEW JERSEY

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